VOLUME XXVII NUMBER 3

THE

JOURNAL OF GEOLOGY

APRIL-MAY 1919

THE BUILDING OF THE COLORADO ROCKIES

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PART I

INTRODUCTION

Many phases of geology involve little more than an understanding of what has taken place at or near the surface of the earth. They can thus be studied more or less directly. A study of diastrophism, however, involves in addition a consideration of what has taken place at greater depths. The visible mountain range is but the outward expression of more deeply operating forces.

Its surficial features may be fairly well appreciated; but its deeper portions are as yet very imperfectly understood. Furthermore the visible expression is material, while the formative process is dynamic. The deeper and dynamic qualities are thus to be unraveled only indirectly by special methods.

In Chamberlin and Salisbury's *Geology*[1] a method has been given for deducing the thickness of the earth shell involved in a given case of folding. This method utilizes the principle that if the amount of crustal shortening be known and also the amount of uplift resulting from the folding, the depth of the deformed block may readily be calculated. It is first tentatively assumed that the folding process has occasioned a change of shape, but has only produced a negligible change of volume, the cubic contents of the deformed block being essentially the same after folding as before. If this assumption be allowed, the product of the original length of the section before folding times the amount of uplift resulting from the folding, will equal the amount of crustal shortening times the depth of the folded zone. Since the indications are that the increase in density and reduction in volume of the deformed mass in cases of ordinary open folding are relatively slight and can if necessary be covered by a corrective factor, this method appears to be trustworthy.

An application of these principles by a trial of this method upon the Appalachian Mountain system led to some very unexpected results.[2] The mountainous belt of central Pennsylvania having been selected for the trial, because folding is so typically displayed there, a strip across the mountains from Tyrone to Harrisburg was measured and its cross-section plotted to scale. The plotted section was then divided into six subdivisions. Applying the method above outlined, the depth of the folded zone was calculated separately for each subsection. The result was the discovery that the two shallowest sections were on the two margins of the folded region, while the deepest portion was in the middle of the range. This would indicate that the shape of the deformed

[1] II (1906), 125–26.

[2] Rollin T. Chamberlin. "The Appalachian Folds of Central Pennsylvania," *Jour. Geol.*, XVIII (1910), 228–51.

Appalachian mass in central Pennsylvania was that of a triangular prism, or wedge, which apexed downward in the middle of the range. Though the wedge-shaped mass was a result quite unexpected, it did harmonize well with various theoretical considerations. In fact it not only appeared reasonable of itself, but seemed to suggest that the principles developed might well be of very general application to mountain building, and might also find some application to plateaus and continental sectors. The wedge-shaped block and wedge dynamics in deformation seemed to open up possibilities along a new line. In view of this, it seemed desirable to apply this method of inquiry to some other mountain systems. For this work the Rocky Mountains were the most available, and as a result of preliminary scouting in the summer of 1913 the section in the vicinity of the Denver and Salt Lake Railroad (Moffat Road) in northern Colorado was selected for the trial. The strip from the Great Plains near Lyons to the Grand Hogback at Glenwood Springs affords perhaps the most characteristic section which can be selected, and is at the same time readily accessible. The special field work for this cross-section was done largely in the summers of 1915 and 1916, besides which short supplementary visits were made in 1917 and 1918, including many trips to points off the section for collateral suggestions.

THE COLORADO ROCKIES

The Rocky Mountain system extends from the Endicott Range of northern Alaska southward as far as central New Mexico, where it gradually fades out. It is a belt of varying width and structure. In Alberta and British Columbia the Rocky Mountain system, according to Daly, is very definitely bounded by the Great Plains on the east and the Rocky Mountain trench on the west.[1] It is bordered on its eastern margin throughout many degrees of latitude by great overthrust faults. In its western part, though faults continue to be numerous, folding becomes more prominent.[2] Characterized thus structurally, the Rocky system continues

[1] R. A. Daly, "Geology of the North American Cordillera at the Forty-ninth Parallel," *Geol. Surv. Can., Memoir 38* (1912), Pl. III and p. 27.

[2] R. G. McConnell, "Report on the Geological Features of a Portion of the Rocky Mountains," *Geol. Surv., Can.*, II (1886), Part D, pp. 31 to 40.

southward nearly halfway across the state of Montana.[1] The regular, linear, faulted chain here loses its distinctiveness and identity, and gives way to an irregular group of scattered mountain clusters in west central and southwestern Montana. Many of these have resulted from igneous outbursts, and exhibit the results of vertically acting forces fully as much as horizontal thrusting. Progressing southward across Wyoming, the ranges of the Rocky group tend to come together more closely in alignment and form a more distinct, continuous chain. But the characteristic structure of the system has changed. Gentle, open folding has replaced thrust faulting as the key structure. This continues across Colorado and into New Mexico.

On many maps the western half of the state of Colorado gives the impression of a tangle of mountains which manifest but little order in arrangement. Such, however, is not the case. The Rocky Mountains enter Colorado from the north as two distinct ranges—the Front Range on the east and the Park Range to the west. Southward these two ranges gradually converge. Though the Park Range dies out in the vicinity of Buena Vista, it is replaced, *en échelon*, by the Sawatch Range. Farther south, in the neighborhood of Salida, the Sawatch chain breaks down and is replaced in turn by the Sangre de Cristo Range. In about the same latitude the Front Range dies down and is replaced south of the Arkansas River by the Wet Mountains. The convergence continues until the two groups of ranges come together near La Veta Pass, from which point southward into New Mexico the entire Rocky Mountain system comprises but a single serrate ridge—the Culebra Range, or southern Sangre de Cristo Mountains. The pattern on the map is represented somewhat approximately by the letter Y, though the two upper branches do not converge quite so rapidly as in the printed letter, and the *en échelon* arrangement of the individual ranges disturbs, to a certain extent, the smoothness of alignment (Fig. 1).

This Y includes all of the Rocky Mountain system proper, which is essentially a folded system in Colorado. West of the

[1] Bailey Willis, "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. of Amer.*, XIII (1902), 305–52; F. H. H. Calhoun, *U.S. Geol. Survey, Prof. Paper 50* (1906), pp. 9–10.

Rockies proper are several scattered mountain groups, such as the San Juan Mountains, Elk Mountains, West Elk Mountains, and Flattop Mountains, which mark spots of excessive Tertiary vulcanism. Structurally they are quite distinct from the folded Rockies proper, and occur as isolated groups in the midst of comparatively undisturbed, flat-lying sedimentary rocks. There are

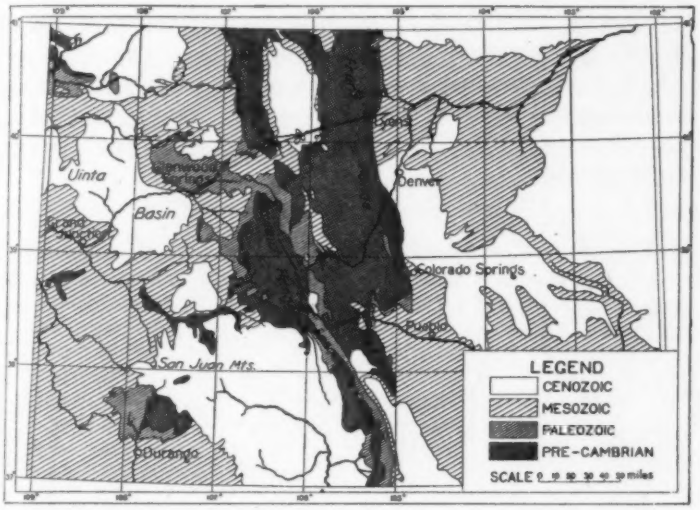

FIG. 1.—Geologic map of Colorado (after R. D. George). The darkly shaded pre-Cambrian areas delineate rather closely the pattern of the Rocky Mountains within Colorado. The ranges converge southward in *en échelon* arrangement roughly suggesting the letter Y.

also some local domelike upwarps in the western part of the state. These local upwarps and the isolated groups genetically related to Tertiary vulcanism should be sharply differentiated from the Rocky Mountains proper—the folded range. The history of the impressive San Juan group has been worked out in detail by Cross,[1] Atwood,[2] and others.

[1] Whitman Cross, *U.S. Geol. Survey, Geol. Atlas*, Needle Mountains, Rico, Silverton, Telluride, and other folios.

[2] W. W. Atwood, "Eocene Glacial Deposits in Southwestern Colorado," *U.S. Geol. Survey, Prof. Paper 95-B* (1915), pp. 22–24.

The differentiation of Colorado's mountains into the Rocky System proper and the subordinate scattered groups mostly associated with Tertiary vulcanism is apparent on either the topographic or the geologic map of the state.[1] The Rocky Mountain Y has a pre-Cambrian granite backbone throughout nearly the whole of its extent. In fact, the pre-Cambrian areas of Colorado, except for a large area of igneous and metamorphic rocks south of the Gunnison River, delineate very well the pattern of the Rocky Mountains. The southward converging of these folded ranges of old rocks, which taper into a single mountain ridge, appeared significant and possibly suggestive of the type of deformation which has taken place. It seemed to imply some sort of wedge dynamics below.

HISTORY OF THE MAIN RANGE

The present Rockies are not the first mountain system developed within the area of Colorado. After a flooding of the region by early Pennsylvanian seas there arose, before the close of the Pennsylvanian period, an ancestral Rocky Mountain range.[2] The elevation of these ancient Rockies has been assigned by Lee "to the period of diastrophism usually called the Appalachian Revolution which wrought world-wide changes in climate, geography, and biology."[3] But Lee recognizes that these ancient Rockies were probably uplifted before the Permian, because sediments derived from the erosion of this ancestral range have formed the Permian beds of the neighborhood. Still further, if the present tendency to place the Fountain sandstone and its equivalents within the Pennsylvanian[4] be correct, this growth of early Rockies must have taken place during the Pennsylvanian, as that period is now defined, since the sediments which made the Fountain sandstone came from the destruction of the newly

[1] The Topographic Map of Colorado. R. D. George, 1913.

[2] Willis T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Misc. Coll.*, LXIX, No. 4 (1918), pp. 5-7.

[3] *Ibid.*, p. 6.

[4] R. M. Butters, "Permian or 'Permo-Carboniferous' of the Eastern Foothills of the Rocky Mountains in Colorado," *Colo. Geol. Survey, Bull. 5* (1913), Part 2, pp. 65–94.

uplifted range. More exact determination of the age of this diastrophism must await closer correlation of these lower Red Beds. But one may well wonder whether this ancestral Rocky Mountain building, which seems to correspond in time with a prominent period of folding in the Arbuckle Mountains of Oklahoma, may not prove to have been closely related to the mid-Pennsylvanian Hercynian orogenic disturbance recognized by Baker and Bowman in the Trans-Pecos region of Texas.[1] On the other hand, the Appalachian diastrophism would seem to have come after a portion at least of the Permian, if the Dunkard beds included in the Appalachian folded series are correctly referred, as is commonly done, to the Permian.

It is not sufficiently clearly recognized by geologists that the diastrophism marking the closing stages of the Paleozoic was a double diastrophism,[2] comprising an essentially world-wide Hercynian orogenic disturbance—the Westphalo-Carbonide movement between the Westphalian and the Stephanian—and a more local Appalachian disturbance, the Permo-Carbonide movement which came after a portion at least of the Permian. It was the earlier, or Westphalo-Carbonide, movement that inaugurated those profound climatic changes which are recorded in widespread evidences of vigorous glaciation within the tropics, in the astonishingly wide prevalence of Red Beds the world over, and which are reflected in turn in great changes in life, and which, in view of the dominating character of these changes and their great significance from many standpoints, may perhaps not unfittingly be chosen as the dividing line between the Paleozoic and the Mesozoic.

Lee states that in few places in the Rocky Mountains can a line of separation be drawn between the Permian and Triassic rocks, while there is a much greater break in sedimentation between the Pennsylvanian limestone and the Permian Red Beds.[3] During the later Pennsylvanian and Permian periods detritus from the

[1] C. L. Baker and W. F. Bowman, "Geologic Exploration of the Southern Front Range of Trans-Pecos, Texas," *Univ. of Texas, Bull. No. 1753* (1917), pp. 107–12.

[2] Rollin T. Chamberlin, "Periodicity of Paleozoic Orogenic Movements," *Jour. Geol.*, XXII (1914), 334–45.

[3] Willis T. Lee, *op. cit.*, p. 7.

newly uplifted mountains was deposited nearby and formed the now prominent non-marine Red Beds. Erosion of the mountains continued through the Triassic and part of the Jurassic, approaching peneplanation before the close of the Jurassic and preparing the way for a marine invasion in Upper Jurassic times.[1] The submergence did not last long, and upon the graded plain abandoned by the sea and the peneplaned area surrounding it the streams of early Comanchean time spread out the sediments of the Morrison formation.[2]

The Cretaceous period was a time of very extensive marine sedimentation in the Rocky Mountain region. Lee has brought out the fact that the Dakota sandstone, and probably also the overlying marine Cretaceous formations, formerly extended uninterruptedly over the areas now occupied by the Colorado Rockies.[3] These Cretaceous beds mark the last great marine invasion of the interior of North America and are represented by a thick stratigraphic column. In waning Cretaceous times the seas shoaled and withdrew, causing marine sedimentation to give way to terrestrial deposits with included coal beds.

Laramide diastrophism.—The Cretaceous period was the long quiet before the storm. At its close the growing stresses within the earth sought relief in folding movements. These were of a pulsatory nature, for at least two distinct periods of folding have been distinguished. In northern Colorado the first of these followed the deposition of the Laramie formation of the Denver Basin. But in southern Colorado no folded formation so late as this has been preserved, owing to the greater erosion there in the interval between the folding and the deposition of the basal Eocene. In that region the last formation affected by the Laramide disturbance which has escaped removal is the Vermejo formation of the Mon-

[1] *Ibid.*, pp. 7–12 and 24–41; also W. N. Logan, "A North American Epicontinental Sea of Jurassic Age," *Jour. Geol.*, VIII (1900), 242–73.

[2] See C. C. Mook, "A Study of the Morrison Formation," *Ann. New York Acad. Sci.*, XXVII (1916), 31–191.

[3] Willis T. Lee, "Relation of the Cretaceous Formations to the Rocky Mountains in Colorado and New Mexico," *U.S. Geol. Survey, Prof. Paper 95-C* (1915), pp. 27–58.

tana group.[1] The exact extent of this diastrophic movement has not yet been satisfactorily determined for the Colorado region, principally for the reason that contacts between the Cretaceous and early Eocene within the folded portion of the range are few and very unsatisfactory, owing to the great amount of erosion which has taken place there. Folded or faulted Cretaceous beds overlain by less disturbed early Eocene strata are not found at many places in Colorado. In Wyoming, however, there are numerous sections in which the Adaville formation (upper Montana and lower Laramie) shows profound folding and faulting followed by extensive erosion before the deposition of the Evanston (early Eocene) beds, which lie in strong discord across the truncated edges of the Mesozoic strata.[2]

In Colorado the Laramide upfolding of the Rockies resulted in a rapid erosion of the newly risen mountains and the accumulation of the Dawson arkose and the Arapahoe conglomerate near Colorado Springs and Denver, and the development of the Raton formation farther south. Some idea of the extent of the upfolding may perhaps be obtained from the amount of erosion which immediately followed. Cross has estimated that post-Laramie erosion had already, in Arapahoe times, removed from portions of the folded belt west of Denver the great total of 14,000 feet of strata, since pebbles derived from various geological horizons down as far as the Trias are found in the Arapahoe beds.[3] In the same way Lee has estimated that the conglomerate at the base of the Raton formation in southern Colorado is stratigraphically more than 18,000 feet above the crystalline and metamorphic rocks that furnished most of the pebbles found in it.[4] Lee, however, recognizes

[1] Willis T. Lee and F. H. Knowlton, "Geology and Paleontology of the Raton Mesa and Other Regions in Colorado and New Mexico," *U.S. Geol. Survey, Prof. Paper 101* (1917), p. 64.

[2] A. C. Veatch and A. R. Schultz, "Geography and Geology of a Portion of Southwestern Wyoming," *U.S. Geol. Survey, Prof. Paper 56* (1907), Pl. IV; A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *U.S. Geol. Survey, Bull. 543* (1914), Pl. III.

[3] Whitman Cross, "Geology of the Denver B asin in Colorado," *U.S. Geol. Survey, Monograph 27* (1896), p. 207.

[4] W. T. Lee, *U.S. Geol. Survey, Prof. Paper 101* (1917), p. 59.

that it is not known that the older sedimentary formations were conformable and once extended continuously over the now uplifted area, but states that in any case the Cretaceous sedimentary rocks are conformable throughout, and in order that pebbles of sandstone from the Dakota and the still older Red Beds could be incorporated in the conglomerate there must have been differential uplift and erosion of more than 4,000 feet. Though making this very safe and modest estimate, Lee has expressed his belief that the actual erosion was probably very much greater than 4,000 feet. An estimate upon the Dawson arkose would probably be of similar import.

Above the Arapahoe in the Denver Basin is the Denver formation, whose composition is of much significance. According to Cross the material of the Denver beds, which must have come from the highlands to the west, may be classed as débris partly from the Archean, partly from sedimentary rocks, and partly from andesitic eruptive rocks.[1] The Arapahoe strata contain little or no fragmental material derived from eruptive rocks, while on the contrary the lowest 900 feet of the overlying Denver beds are composed largely of andesitic materials and contain very little granitic or sedimentary débris. Cross says: "The andesitic masses which furnished the materials for the lower part of the Denver sediments were so situated as to effectively prevent the access of all Archean and sedimentary débris to the sea of that epoch. That is to say, the Archean and sedimentary rocks in the mountainous area drained by the tributaries of the Denver sea must have been covered by andesitic lava flows so that no material other than the eruptive débris could appear in the Denver sediments, from this, the prominent source, until erosion had laid bare, here and there, small areas of granite, of gneiss, or of sandstone."

More direct evidence of these floods of andesite, the postulated source of much of the material of the Denver sediments, has been found in Middle Park, where there is a thick formation of andesitic breccias and tuffs with conglomerate and sandstone resting unconformably upon the Cretaceous, and which is comparable to the

[1] Whitman Cross, *op. cit.*, pp. 199–206.

Denver formation in lithological character and in its fossil plants.[1] Along the Grand River, in the line of the section which was measured as the basis for this present study of the Rocky Mountain deformation, the Middle Park formation outcrops continously for a distance of $4\frac{3}{4}$ miles. Its structure, as was first noted in the very excellent description by Marvine,[2] is basin-like. On the eastern limb of the syncline the steeply inclined, westerly dipping beds of the basal portion of this formation, form the conspicuous mountain ridge through which the Grand River flows at Windy Gap, $3\frac{1}{2}$ miles northwest of Granby. Westward toward the middle of the basin the dip rapidly lessens, and for several miles is not far from horizontal, but farther west the lower beds of the volcanic series emerge again about 2 miles east of Hot Sulphur Springs.

At Windy Gap the Middle Park formation consists of a series of breccias, tuffs, conglomerates, and sandstones dominantly of andesitic derivation. In the lower portion there are several hundred feet of coarse breccia containing many cobbles and angular fragments of andesite up to six inches in diameter. Higher up in the series the material becomes finer, and rounding by water action becomes more prominent. Within the first five hundred feet of the formation no evidence of granitic materials was observed. The pre-Laramide formations at this stage supplied very little detritus to be mixed in with the andesitic derivatives. But in time the lithological character of the accumulation underwent a change as new sources of material became available. About 1,000 feet stratigraphically above the base of the formation some very striking conglomerates appear in the hills immediately west of the Windy Gap Ridge. Well-rounded cobbles of four or five inches represent the average coarseness, though bowlders of a foot or more in diameter are not difficult to find. These cobbles are of granitic rocks and various fine-grained porphyries, particularly grayish-green andesite. The only available source for the granites is the

[1] Whitman Cross, "The Post-Laramie Beds of Middle Park, Colorado," *Proc. Colo. Sci. Soc.*, IV (1891–93), 192–214.

[2] A. R. Marvine, "Report on Middle Park," *U.S. Geol. and Geog. Survey of Colorado* (Hayden), 1873, pp. 154–92.

pre-Cambrian complex, while the porphyries were as obviously derived from the flows of the Middle Park formation itself. The old granites and the Tertiary effusives are in nearly equal proportions. Above this conglomerate for another thousand feet are various arkosic sandstones and coarse conglomerates whose material has been derived from both the old granites and the young andesites. Pebbles of white and purplish vitreous quartzite are conspicuous in places.

The import of this formation is that, either accompanying a late stage of the post-Laramie folding or soon after it, there were extensive outbursts of andesite in this portion of the Colorado Rockies. These flows were either so vast or else were so located relative to the basins where sediments accumulated, that they furnished a very large part of the detritus which made up the lower portion of the Middle Park formation, as urged by Cross, while the Archean granite contributed practically nothing. But later, after these volcanics had suffered much erosion, or else there had occurred further uplifting along the granite core of the range, or both, the granite areas supplied much coarse pebble and cobble material to the sediments which were accumulating in this basin.

Early Tertiary folding.—Since deposition this Middle Park formation has suffered a period of folding which has accentuated the structural basin by causing the basal volcanics on the eastern margin of the syncline to dip westward at angles of 50°–60° and the same series on the western margin to dip eastward at angles up to 30°. The upper beds of the formation exposed in the middle of the syncline possess only very gentle undulations which cause them to depart but little from a horizontal position.

The time of the folding movement which disturbed these beds was not closely determined in this present study. In any case it was post-Middle Park and pre-Uinta, for after the folding a long period of denudation had greatly changed the region before the beds classed as Uinta were laid down. It is possible that this is to be correlated with a prominent folding period which has been recognized in the mountains of Wyoming, and which can be more closely timed. There the folding and faulting occurred between the Fowkes formation of the Lower Wasatch and the Knight formation

of the Upper Wasatch, and is represented, according to Veatch, by a break which amounts to perhaps 5,000 feet of strata.[1] But the older, post-Laramie break amounts to over 20,000 feet, and Veatch has expressed the opinion that the folding following the Lower Wasatch should perhaps be regarded as of much less relative significance than this comparison of figures might indicate, because the movements of the second disturbance were along the lines of weakness produced by the first. As to correlation, Veatch is conservative, placing the 6,000 feet of strata between these two breaks in the debatable ground between the known Cretaceous and Tertiary.

Along the western margin of the Rocky Mountain belt in the Colorado section here studied, the Grand Hogback upturn involves the Wasatch beds as fully as the Cretaceous. This may be observed to the west of Glenwood Springs, both north and south of the Grand River. At Piceance Gap to the northwest both the Wasatch and Green River beds are included in the monoclinal fold according to Gale.[2] Farther west in the Uinta Basin of Utah the Wasatch has been folded with the Cretaceous.[3] Whether this flexing on the western borders of the Rocky belt is to be correlated with the Middle Park folding within the range is uncertain. Irrespective of this it is peculiar in manifesting certain characteristics of basin-like subsidence and downwarping.

R. C. Hills has described this early Tertiary folding exhibited in certain portions of the Sangre de Cristo Range as post-Bridger, because the Huerfano beds were involved.[4] To this period of folding he has also assigned the flexing of the Grand Hogback, as well as rather widespread folding on the east flank of the front range.[5] Hills is the authority for the belief that the post-Bridger folding

[1] A. C. Veatch, *U.S. Geol. Survey, Prof. Paper 56* (1907), p. 75.

[2] Hoyt S. Gale, "Coal Fields of Northwestern Colorado and Northeastern Utah," *U.S. Geol. Survey, Bull. 415* (1910), Pl. XIII.

[3] C. T. Lupton, "The Blacktail Mountain Coal Field, Wasatch County, Utah," *U.S. Geol. Survey, Bull. 471* (1912), Pl. LXII.

[4] R. C. Hills, *U. S. Geol. Survey Geol. Atlas, Walsenberg Folio*, No. 68 (1900) pp. 2–3.

[5] R. C. Hills, "Orographic and Structural Features of Rocky Mountain Geology," *Proc. Colo. Sci. Soc.*, III (1888–90), 408–19.

in Colorado was nearly as widespread and equally as intense as the post-Laramie folding.[1] It followed very closely the older Laramie lines of flexure.

The post-Middle Park folding was followed by a long period of erosion in the Colorado Front Range. Erosion in fact must have been steadily at work on the main anticlines of the Colorado Rockies since their arching in the Laramide diastrophism. This long continued denudation greatly reduced the country, as is known from the fact that beds regarded as Uinta in age[2] were laid down directly upon the Archean granite over wide areas in the Grand River region of Grand County. The broad valleys and basins of the region no doubt received deep fillings of detrital material, as the country was brought toward a common level by degradation of the higher areas and aggradation of the lower. The Upper Eocene beds thus deposited exhibit in places an appreciable departure from horizontality, giving rise to a slight waviness in structure, but they seem to have suffered no pronounced folding. This warping of the Upper Eocene beds suggests that in this region there was a mild expression of the mid-Tertiary diastrophism which developed more strongly near the Pacific Coast and elsewhere.

Peneplanation.—After one or more cycles of erosion of whose details little is known, the granite ranges became an imperfect plain, above which unreduced areas remained as scattered monadnocks from 500 to 2,500 feet in height.[3] This peneplain, if such an imperfectly reduced area may be designated by that term, must have extended throughout the region of the Colorado Front Range, for remnants of it are still preserved at many points in different parts of the range. In the neighborhood of the Lyons-Grand River section, whose study constitutes the basis for the investigation in hand, these flats form conspicuous portions of the continental divide in Flattop Mountain and some of its immediate neighbors in Rocky Mountain National Park (Fig. 2). The name Flattop is correctly descriptive of an extensive flattish portion

[1] R. C. Hills, "Orographic and Structural Features of Rocky Mountain Geology." *Proc. Colo. Sci. Soc.*, III (1888–90), p. 443.

[2] Geologic Map of Colorado. R. D. George, 1913.

[3] W. M. Davis, "The Colorado Front Range," *Ann. Assoc. Am. Geog.*, I (1911), 31.

of the divide in a region of steep-sided peaks and precipitous cirque walls. The bench mark on this summit flat records an elevation of 12,364 feet. Views from the nearby peaks give the observer an excellent idea of this old peneplain. South of the Lyons-Grand River section more of the peneplain is still preserved on the continental divide. The crest of the range from the neighborhood

FIG. 2.—The peneplain on the continental divide. Looking southeast across Flattop Mountain (12,364 feet) to Long's Peak, a rugged peak carved from an unreduced remnant rising above the peneplain level. In the immediate foreground are the upper cirque walls of Spruce Canyon. Several other steep-walled cirques head back into Flattop but are barely visible in this view.

of Arapahoe Peak to James Peak, when viewed from the Windy Gap Ridge west of Granby, presents an almost horizontal skyline whose elevation is shown by the map of the Central City quadrangle to be very close to 12,000 feet. Continuing the vision to the south of the monadnock group comprising James Peak, Mt. Eva, and Mt. Flora, the eye is again impressed by the level sky line which extends onward for many miles with little departure from the 12,000 foot elevation.

The age of this peneplain was not determined. No ready means of dating it was found in the time at disposal, and exhaustive search was not felt to be vital to the immediate problem in hand, though admittedly very important in the history of the range and that of the general region. Perhaps something may be learned from a comparison with more favorably situated peneplains in adjoining states. The pronounced peneplain upon the Wind River Range of Wyoming has been assigned to the middle of the Miocene by C. L. Baker.[1] Baker believes that this peneplanation was interrupted, probably later in the Miocene, by an uplift, both regional and orogenic, along the lines of the earlier Laramide movement. Westgate and Branson, however, did not feel justified in dating the peneplain more closely than mid-Tertiary.[2] Blackwelder, on the other hand, believes that the Wind River summit peneplain is of Pliocene age, for which he gives a well considered argument.[3]

In the Laramie region of southeastern Wyoming, Blackwelder has described Pole Mountain and the Medicine Bow plateau surface as remnants of a peneplain developed by the Eocene cycle of denudation, while the Sherman peneplain, at somewhat lower elevation, represents in his opinion a Pliocene date.[4] These two erosion levels, if such they be, are not far apart near the Wyoming-Colorado line, indicating that but little uplift took place between these stages; but southward in the Front Range of Colorado the relief of the country becomes steadily greater. In the Long's Peak region extensive flats are found east of the main range in the neighborhood of 8,000 feet, which is not far from the Sherman level in the Sherman quadrangle, but the summit peneplain on the continental divide is here at an altitude of approximately 12,000 feet. The Great Plains abut the foothills in the Sherman region at an elevation of about 7,000 feet, ignoring the

[1] Charles Laurence Baker, "Notes on the Cenozoic History of Central Wyoming," *Bull. Geol. Soc. Amer.*, XXIII (1912), 73.

[2] L. G. Westgate and E. B. Branson, "The Later Cenozoic History of the Wind River Mountains, Wyoming," *Jour. Geol.*, XXI (1913), 144–47.

[3] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *Jour. Geol.*, XXIII (1915), 193–207.

[4] Eliot Blackwelder, "Cenozoic History of the Laramie Region," *Jour. Geol.*, XVII (1909), 429–44.

river valleys which have cut well below this level; east of Long's Peak the plains have an elevation of only 5,000 feet above the sea. The greater elevation of the Front Range in Colorado is the result of greater upbowing of the old peneplain surface in that latitude.

On the Sherman (Wyo.) sheet close to the Wyoming-Colorado line, the Sherman peneplain level is in the neighborhood of 7,700 feet above the sea. On the Livermore (Colo.) sheet next south the plain rises from about 7,000 near the sedimentary hogbacks to 8,000 feet at the west margin of the sheet. On the Mt. Olympus sheet next south the general elevation of the plain is not very different, but on the Boulder sheet adjoining Mt. Olympus on the south the plain rises from 6,500 feet elevation near the city of Boulder to approximately 9,000 feet at the west margin of the sheet near the mining camp of Ward. While there may well be some minor levels included, these elevations constitute a very evident erosion plain which slopes toward the east. The slant of the plain becomes progressively steeper as it is followed southward from Sherman, Wyoming, to Boulder, Colorado, indicating a greater upwarp of the range in the latitude of Boulder.

Davis considered this old erosion plain to have been once continuous with the so-called summit peneplain whose remnants are today seen on the continental divide at an elevation of 12,000 feet.[1] If so, it would mean that the inclination of the plain becomes greater as it nears the divide. It is natural enough that there should have been sharper tilting along the axis of the range. In the region crossed by my section, however, the evidence did not seem to be altogether conclusive. There may be two plains representing different cycles. If so, this would suggest some upwarping between and would have a bearing upon the age of the summit peneplain. But if, on the other hand, the summit plain and the lower plain to the east are truly parts of the same surface of denudation, the rather obvious recency of the latter would indicate that the summit peneplain is of late Tertiary age. The erosion plain extending from Allen's Park and Ward to the foothills near Boulder must clearly be as late as the Pliocene.

[1] W. M. Davis, *op. cit.*, p. 31 and Fig. B2, pp. 76–77.

West of the continental divide along the line of the Grand River section, remnants of a former surface of little relief are observed at various points. In Pliocene times this region, if not brought to the condition of a true peneplain, was at least greatly reduced and many extensive flattish areas developed. Preserved portions of these are seen today on the western uplands of the section at elevations for the most part between 9,000 and 10,000 feet. The Lyons-Grand River cross-section given later in this paper seems, however, to belie this statement, but that is because the drawn section closely follows the course of the Grand River and only in a few places does it rise to the upland peneplain level.

Upbowing.—Since the formation of this late Tertiary peneplain, it has been bowed upward along an axis which corresponds approximately with the present crest of the Front Range. General uplift involving some little warp also affected the region west of the Front Range and accentuated the height of several of the ranges. The movement in the Front Range was a gentle tilting in the latitude of Long's Peak, though in the foothills it may have been accompanied by normal faulting. Farther south, in the vicinity of Castle Rock and Colorado Springs, Richardson's sections of the Front Range foothills show the Dawson arkose of the early Eocene to be steeply inclined, and cut by a set of normal faults, which are there an important part of the foothill structure.[1] Finlay has placed this period of disturbance within the Pliocene Period.[2]

This uplift has given the Front Range much of its present elevation above the Great Plains to the east. Streams rejuvenated by the uplift have since carved deep canyons, which head far back in the high level plain. Leading back from the plains to the open uplands of Estes Park and Allen's Park, where roads are possible in almost any direction, are the wonderful scenic canyons of the Thompson River and St. Vrain Creek, which are young in the present cycle of erosion. On the west side of the continental

[1] G. B. Richardson, *U.S. Geol. Survey, Geol. Atlas, Castle Rock Folio*, No. 198 (1915), pp. 10–11.

[2] George I. Finlay, *U.S. Geol. Survey, Geol. Atlas, Colorado Springs Folio*, No. 203 (1916), pp. 13–14.

divide the Grand River sweeps swiftly through the beautiful Byers, Gore, and Grand River canyons on its way westward, showing that, while the extent of the uplift varies from place to place, the Rocky Mountain belt in this latitude was bowed up throughout its full width. These are among the finest canyons in Colorado and through their high, rugged walls they testify to the

FIG. 3.—Rugged mountains sculptured from a smooth-sloped monadnock rising above the peneplain on the continental divide. Long's Peak (14,255 feet) from Taylor Peak (13,150 feet). Remnants of the smooth monadnock surface are seen on the right-hand side of the photograph in McHenry's Peak and Chief's Head. This surface was seemingly once continuous with the flat summit of Long's Peak. Glaciers stoping backward have cut profound cirques into the old surface.

extent and comparative recency of the uplift which has renewed the cutting power of the Grand River. Increased erosion on the softer sedimentary strata east of the Front Range granite area has lowered the Great Plains immediately adjacent to the foothills, thus further uncovering and sculpturing into hogbacks the more resistant beds of the steeply upturned sedimentary series of the foothill belt. The map of the Livermore Quadrangle suggests that there were

at least two distinct stages in this process. Since the weaker strata of the plains reached a stage of advanced old age, two episodes of erosion have left their impress there, according to the studies of Davis.[1]

Quaternary glaciation has also greatly modified the details of the mountainous belt. By the cirquing and stoping process, serrate peaks and sharp ridges have been carved and sculptured out of the rounded monadnocks and remnants of the summit peneplain (Fig. 3). Rounded U-shaped valleys with capacious cirques testify to the potency of glacial erosion in the adjoining valleys.

[1] W. M. Davis, *op. cit.*, p. 31. See also N. M. Fenneman, "Geology of the Boulder District, Colorado," *U.S. Geol. Survey, Bull. 265* (1905), Fig. 1 and Pl. IIIA.

[*To be continued*]

NOTES ON THE GEOLOGY OF GEORGIA

S. W. McCALLIE
Atlanta, Georgia

ARCHEAN SYSTEM

The geological history of Georgia begins with the ancient Crystalline rocks, the greater part of which are supposed to be of Archean age. These rocks form a northeast-southwest belt about 125 miles wide traversing the northern part of the state and are a part of the great belt of ancient Crystallines extending from northeastern New York to eastern Alabama (Fig. 1). The areal extent in Georgia is about 15,000 square miles, or approximately one-fourth of the state. They occupy all of the physiographic division known as the Piedmont Plateau, and a part of the Appalachian Mountain division. To the northwest they are limited by the metamorphic Cambrian rocks and to the south by the Tertiary. The latter boundary is sharp and distinct, while the former is ill-defined. These rocks are here described under the following names: Carolina gneiss, Roan gneiss, and granites.

The *Carolina gneiss*, so called from its wide distribution in the Carolinas, where it has been studied by Keith and others, is the prevailing rock of the ancient Crystallines of Georgia (Fig. 2). Broadly speaking, the formation may be correlated with the Baltimore gneisses of Maryland and the Stanford and Fordham gneisses of New York.

The most abundant, widespread, and typical rocks of the Carolina formation are schists, largely micaceous and garnetiferous, and biotite gneiss. In addition there occur in more or less restricted areas graphitic schist, quartzitic schist, and schistose conglomerate. The most persistent character of these rocks is the schistose and bended structure due to the segregation of the component minerals along definite lines. They are the oldest rocks of the state and may be considered the country rock into which the Roan gneiss and

GEOLOGICAL SURVEY OF GEORGIA
S.W. McCALLIE, State Geologist
OUTLINE
GEOLOGICAL MAP
OF
GEORGIA
LEGEND
Quaternary
Tertiary
Cretaceous
Paleozoic
Altered Paleozoic
Archean
TENN.
N. C.
S. C.
DALTON
ELLIJAY
ROME
CARTERSVILLE
GAINESVILLE
ATHENS
MARIETTA
ATLANTA
GRIFFIN
AUGUSTA
MILLEDGEVILLE
MACON
OCMULGEE RIVER
OGEECHEE RIVER
ALA.
COLUMBUS
DUBLIN
AMERICUS
SAVANNAH
CUTHBERT
ALBANY
ALTAMAHA RIVER
BLAKELY
WAYCROSS
BRUNSWICK
THOMASVILLE
VALDOSTA
FLA.
SCALE
100 MILES

FIG. 1

COLUMNAR SECTION

ALTERED PALEOZOIC AND ARCHEAN ROCKS OF GEORGIA

SYSTEM	FORMATION	COLUMNAR SECTION	THICKNESS IN FEET
METAMORPHIC CAMBRIAN	NOTTELY QUARTZITE		200 +
	ANDREWS SCHIST		50
	MURPHY MARBLE		50-300
	VALLEYTOWN FORMATION		1200-2000
	BRASSTOWN SCHIST		1200-1500
	TUSQUITEE QUARTZITE		20-600
	NANTAHALA SLATE		1000-2000
	GREAT SMOKY FORMATION		5000-6500
	UNCONFORMITY		
ARCHEAN	GRANITE		
	PYROXENITE, DUNITE, AND SERPENTINE		
	ROAN GNEISS		
	CAROLINA GNEISS		

FIG. 2

granites have been intruded. The series is supposed to be largely of igneous origin, though sediments undoubtedly occur in certain localities, as shown by the graphitic schist, quartzitic schist, and schistose conglomerate.

The *Roan gneiss* is a series of basic igneous rocks including hornblende schist, hornblende gneiss, and schistose diorite. These rocks occur in belts varying from a few feet to hundreds of rods in width and often cut the Carolina gneiss, into which they have been intruded at rather high angles. Less abundant and only locally developed are pyroxenites, dunites, and serpentine belonging to the same series.

The *granites* are widely distributed and in places cover areas of many square miles. They are prevailingly biotitic and generally show gneissic structure. In age they are supposed to be largely pre-Cambrian, though the more massive varieties, such as Stone Mountain near Atlanta, are probably younger. The granites unquestionably represent two or more periods of intrusion.

CAMBRIAN SYSTEM

ALTERED CAMBRIAN

The Cambrian system is divided into the altered and unaltered Cambrian. The altered or metamorphic Cambrian rocks, so far as known, are mainly confined to an irregular belt, varying in width from eight to twenty-five miles, in the northwestern part of the state. The belt lies immediately west of the Archean rocks and embraces in its northern extension a greater part of the Appalachian Mountain physiographic division of the state. These rocks belong to the Ocoee group of Safford and were long regarded as of Algonkian age. However, fossils of Lower Cambrian age are found as far down as the middle of this group of strata in Tennessee and North Carolina, and the strata below the fossil-bearing beds are conformable and not materially different in character. In addition to this main belt there is a narrow belt known as the Brevard schist entering the state from South Carolina northeast of Gainesville and stopping about five miles west of Atlanta. It seems quite probable that the metamorphic Cambrian originally overlay the Crystallines as far east as Atlanta and possibly beyond.

This group of altered sediments has been studied in detail only in one section of the state, namely, the area covered by the *Ellijay Folio*. In that locality the rocks have been described by La Forge and Phalen under the following formation names: (1) Great Smoky formation, (2) Nantahala slate, (3) Tusquitee quartzite, (4) Brasstown schist, (5) Valleytown formation, (6) Murphy marble, (7) Andrews schist, and (8) Nottely quartzite.

The *Great Smoky formation*, in the Ellijay quadrangle along its eastern margin, lies upon the Carolina gneiss, although the immediate contact is difficult to define, as in that section the latter is made up largely of graywacke and conglomerate, which are very similar in lithological character to the base of the Great Smoky. The formation consists of a great thickness of conglomerate, graywacke, sandstone, quartzite, slate, mica schist, garnet schist, and staurolite schist. The conglomeratic phase is best developed to the east and north, while to the west and south the mica schist, quartzite schist, and slates prevail. The Great Smoky formation is a part of Safford's Ocoee series and has been provisionally correlated with the Cochran and the Thunderhead conglomerates of Tennessee and North Carolina. West of the Ellijay quadrangle and below the Great Smoky formation occur considerable areas of the Wilhite slate and the Gilmer formation, but their detailed structure and relations have not yet been worked out.

The *Nantahala slate*, near the Georgia-North Carolina line, includes principally blackish and dark-gray slates, though white quartzite and staurolitic schist are also more or less plentiful. Farther south in the vicinity of Ellijay and beyond, the formation is mainly graphitic schist with but few siliceous beds. Its distribution is confined to the eastern margin of the metamorphic area, where it forms narrow belts rarely over a mile in width.

The *Tusquitee quartzite*, which is apparently confined to the Ellijay quadrangle, consists almost entirely of white quartzite with an occasional bed of conglomerate. Owing to the persistent character of the formation and its difference in color from the associated rock, it is an excellent guide in working out the stratigraphy of the region, which is much complicated by numerous faults and folds.

The *Brasstown schist*, where not displaced by faulting, has a similar distribution to the Tusquitee quartzite, though it does not extend so far south as the latter. It is made up of banded slate and ottrelite schist having usually a dark, bluish color. Owing to its limited distribution it is only of minor stratigraphic importance.

The *Valleytown formation* consists of biotite schists, sericite schist, and mica gneiss, with a few beds of quartzite and conglomerate. In the Ellijay quadrangle south of Cherrylog it is described as a nearly homogeneous mass of sericite, mica schist, and siliceous slate, with some talcose material. The occurrence of graphitic schist beds are noted in the formation between Toccoa River and Ellijay. The formation is usually valley-forming, though north of Blue Ridge, extending to the state line, it forms a rather prominent ridge, as well as the narrow valleys on either side.

The *Murphy marble*, from an economic standpoint, is the most important of the metamorphic group of rocks in the state. It consists of holocrystalline limestone which in places becomes magnesian. The magnesian phase of the formation is commonly fine-grained, while the high-calcium phase is coarse-grained. It is usually white but in places is more or less banded or mottled with black owing to the presence of graphite. The formation enters the state from North Carolina in the vicinity of Culberson, from which point it continues southwest in one or more narrow belts, with a few interruptions due to faulting, to a point a few miles beyond Tate, Pickens County, the seat of Georgia's great marble industry. Marble very similar in texture and composition occurs many miles farther to the southwest in Haralson County, near Buchanan, which is supposed to be the southern extension of the Murphy marble. The formation is probably the equivalent of the Shady limestone, an unaltered magnesian limestone hereafter to be described.

The *Andrews schist* is a comparatively thin, unimportant calcareous schist overlying the Murphy marble near the Georgia-North Carolina line, and like the overlying Nottely quartzite is of very limited extent. It is made up almost entirely of dense quartzite which is highly resistant to weathering and is therefore ridge-forming.

UNALTERED CAMBRIAN

The Unaltered Cambrian rocks occupy the northwestern part of the state and are divided into the Lower, the Middle, and the Upper divisions, the first named being subdivided into the Weisner quartzite, Shady limestone, Cartersville formation, Apison shale, and Rome formation (Fig. 3).

The *Weisner quartzite*, which is the southern extension of a part of the Chilhowee sandstone of Tennessee, forms a prominent series of ridges and hills along the eastern margin of the Appalachian Valley as far south as Cartersville and a few miles beyond. At this point it is cut out by the Cartersville fault, but farther to the southwest it again appears in a small area near Esom Hill, where it forms the northern extension of a large area just across the state line in Alabama. The lithological character of the Weisner quartzite as described by Hayes is fine-grained and vitreous, though the formation also contains some beds of fine conglomerate and considerable siliceous shale. A few imperfectly preserved fossil remains, including brachiopods, corals, and worm tubes, all supposed to be Lower Cambrian, have been found in the formation in the vicinity of Cartersville and Emerson.

The *Shady limestone* lies immediately above the Weisner quartzite, and it has a like distribution. The formation consists chiefly of gray magnesian limestone usually massive but in places shaly and siliceous. It is of very great economic importance, as associated with its weathered product, occur more or less extensive deposits of barytes, iron ore, and manganese ore. Fossils are almost entirely absent, though in the vicinity of Cartersville a fossil sponge, a lower Cambrian form, has been found.

The *Cartersville formation*, as recently defined by Shearer, is known only in the Cartersville district. It is supposed to occupy the same position in the stratigraphic column as the Watauga shale of Tennessee and the Apison shales of Tennessee and Georgia. The formation has a limited distribution, being confined to one main belt less than twenty miles long. It consists mainly of highly aluminous shales, which are remarkable for their high potash contents, often as much as 10 per cent K_2O. Associated with the shales, which are chiefly of a gray or purplish color, there are often

COLUMNAR SECTION
PALEOZOIC ROCKS OF GEORGIA

ERA OR SYSTEM	PERIOD OR GROUP	FORMATION	COLUMNAR SECTION	THICKNESS IN FEET
CARBONIFEROUS	PENNSYLVANIAN	WALDEN SANDSTONE		930
		LOOKOUT FORMATION		500
	MISSISSIPPIAN	PENNINGTON SHALE		780+
		BANGOR LIMESTONE (PROBABLY TIME EQUIVALENTS)		900
		FLOYD FORMATION (PROBABLY TIME EQUIVALENTS)		1,500+
		FORT PAYNE CHERT		200
DEVONIAN	UPPER	CHATTANOOGA BLACK SHALE		20
	MIDDLE (ABSENT)			
	LOWER	FROG MOUNTAIN SANDSTONE AND ARMUCHEE CHERT		40
SILURIAN	UPPER (ABSENT)			
	MIDDLE NIAGARAN	ROCKWOOD FORMATION		1,600
	LOWER (ABSENT)			
ORDOVICIAN	UPPER	(WESTERN BASIN) CHICKAMAUGA FORMATION / (EASTERN BASIN) ROCKMART SLATE		2,500+
	MIDDLE	CHICKAMAUGA LIMESTONE		200
	LOWER	KNOX DOLOMITE		5,000
CAMBRIAN	UPPER CAMBRIAN OR SARATOGAN	CONASAUGA SHALE AND LIMESTONE		2,000
	MIDDLE CAMBRIAN OR ACADIAN			
	LOWER CAMBRIAN OR GEORGIAN	ROME FORMATION		3,500
		APISON SHALE		1,000
		CARTERSVILLE FORMATION		1,000
		SHADY LIMESTONE		1,100+
		WEISNER QUARTZITE		2,500+

FIG. 3

found thin layers of feldspathic sandstone and quartzite, but these form only a minor part of the formation as a whole.

The *Apison shale* consists of varicolored argillaceous shales developed only in limited, elongated areas in Whitfield and Catoosa counties. Although the Apison is evidently approximately equivalent to the Cartersville formation in age, the exposures are in the western part of the valley.

The *Rome formation* consists of sandstone and shale and is confined to two belts near the center of the Appalachian Valley. The main belt, which is rarely more than two miles wide, extends from near Cave Spring, Floyd County, northeast through Rome to a point within about three miles northwest of Calhoun in Gordon County. The other belt commences near Villanow in Walker County and continues to the Georgia-Tennessee line a few miles northeast of Ringgold. A third belt which Hayes placed in this formation on the basis of stratigraphic position is above described as the Cartersville formation. Immediately overlying the Rome formation and apparently without any stratigraphic break are the only representatives of Upper Cambrian, namely the Conasauga formation and the lower division of the Knox dolomite formation.

The *Conasauga formation*, with the exception of the Knox dolomite, covers the largest surface area of any of the Cambrian series of Georgia. It is especially well developed along the eastern side of the Appalachian Valley, where it occurs in two main elongated but broad belts. The easternmost of these belts continues south from the Georgia-Tennessee line from Tennga to a point a few miles south of Cartersville, where it is cut off by the Cartersville fault, while the other belt, after being divided into minor belts and at points uniting with the easternmost belt, continues to the Alabama state line by way of Rome. Farther to the west are three narrow belts, one of which, lying to the west, traverses the entire northwestern corner of the state by way of Lafayette. The upper part of the formation is made up largely of olive-green and yellowish-green argillaceous shale, but the lower part consists mainly of grayish and bluish limestones locally oölitic and interstratified with the shale. The Conasauga formation contains an

abundant Cambrian fauna which has been studied by Professor C. D. Walcott.

The *Knox dolomite* is divided by an unconformity into a lower and upper division. The upper division on paleontological evidence has been referred to the Ordovician system and the lower to the Cambrian. The formation as a whole consists of a great thickness of magnesian limestones with much chert in places. It occurs in a large number of broad and narrow belts traversing the Appalachian Valley.

ORDOVICIAN SYSTEM

The *Chickamauga formation* represents both the Middle and the Upper group of the Ordovician system. It consists of sediments laid down in two separate basins. The rocks in the western part of the valley consist of interbedded limestones and shales outcropping in a number of long, narrow belts, while in the eastern part of the valley the formation is divided into the Chickamauga limestone and the Rockmart slate. The latter consists chiefly of dark-colored slates, with a few thin beds of sandstone and some limestone usually high in calcium.

SILURIAN SYSTEM

The *Rockwood formation*, which unconformably overlies the Chickamauga formation, is the only representative of the Silurian system. It consists of olive-green shales and thin-bedded sandstone, with one or more beds of fossiliferous iron ores. It occurs only in the western part of the Appalachian Valley, where it forms narrow belts at the base of the higher ridges and mountains capped with Carboniferous rock.

DEVONIAN SYSTEM

The *Chattanooga black shale* and the *Armuchee chert* are the only representatives of the Devonian system in Georgia. These two formations are separated from each other by an unconformity and are supposed to represent the Upper and Lower Devonian respectively, the middle part of the system being absent. The black shale, which attains a thickness of not more than twenty feet, is confined to the western part of the valley, where it occurs

in narrow outcrops with a linear distribution coextensive with the Rockwood formation. The Armuchee chert, which consists of bedded chert and thin beds of reddish-brown sandstone, is confined to a few small areas north of Rome.

CARBONIFEROUS SYSTEM

The *Fort Wayne chert* is the lowest member of the Mississippian group of the Carboniferous system and unconformably overlies the Chattanooga black shale. It consists essentially of siliceous limestone, with layers and nodules of chert made up in places largely of crinoid stems. The formation in the western part of the Appalachian Valley occupies narrow belts, while north of Rome it covers large, irregular areas.

The *Floyd shale* and the *Bangor limestone*, which also belong to the Mississippian group are probably stratigraphically equivalent, though one is largely shale and the other limestone. The former is best developed along the narrow valleys at the base of Lookout and Sand mountains, while the other occurs in numerous narrow belts in Floyd County and the adjacent counties both north and east of Rome.

The *Pennington shale* unconformably overlies the Bangor limestone and forms the uppermost series of the Mississippian group. It consists largely of shale, with sandstone in the upper portion. Its linear distribution is coextensive with the Bangor limestone.

The *Lookout formation* and the *Walden sandstone* are both members of the Pennsylvanian group. They are best developed in Lookout and Sand mountains, which constitute what is known as the Cumberland Plateau physiographic division of the state. They consist of sandstones, conglomerates, shales, and a number of commercial coal seams.

CRETACEOUS SYSTEM

The Cretaceous system, which rests unconformably on the old crystalline rocks, is confined to a narrow, irregular belt traversing the middle portion of the state in a southwest direction from Augusta to Columbus by Milledgeville and Macon. The total area covered by this system of rocks is approximately 250 square

miles. It is divided into an upper and a lower series, the latter being further divided into two formations, namely the Ripley and the Eutaw (Fig. 4).

The *Lower Cretaceous*, so far undifferentiated, lies immediately upon the crystalline rocks below and is unconformably overlain by the Eutaw. The basal unconformity represents an enormous time interval, including all Paleozoic time and the Triassic[1] and Jurassic periods of the Mesozoic time. The formation is made up predominantly of coarse-grained cross-bedded, arkosic sand, with a subordinate amount of white clays in the form of lenses. It forms an irregular belt varying from two to ten miles in width and extending entirely across the state.

The *Eutaw and Ripley formations*, each divided into two or more members, occupy an elongated area immediately south of the Lower Cretaceous between the Ocmulgee and Chattahoochee rivers. Both formations are of marine origin and consist mainly of calcareous, micaceous sand and dark-gray sandy clay, with some thin-bedded impure limestone. The upper member of the Ripley formation is unconformably overlain by the Midway formation, the basal member of the Eocene series.

TERTIARY SYSTEM

The Tertiary system of rocks has a far greater areal extent than any other system in the state. With the exception of a narrow belt of Quaternary along the Atlantic seaboard and narrow irregular belts of Cretaceous immediately south of the ancient Crystallines, it covers the entire Coastal Plain which comprises more than one-half the area of the state. The system is represented by the following series: the Eocene, the Oligocene, the Miocene, and the Pliocene. The first named is divided into five formations, the Midway, the Wilcox, the McBean, the Ocala, and the Keg Creek. The Keg Creek and the Ocala limestone formations both belong to the Jackson group, while the McBean formation belongs to Claiborne group.

[1] The Triassic rocks in Georgia are represented by diabase dikes which are widely distributed over the Piedmont Plateau.

COLUMNAR SECTION
COASTAL PLAIN OF GEORGIA

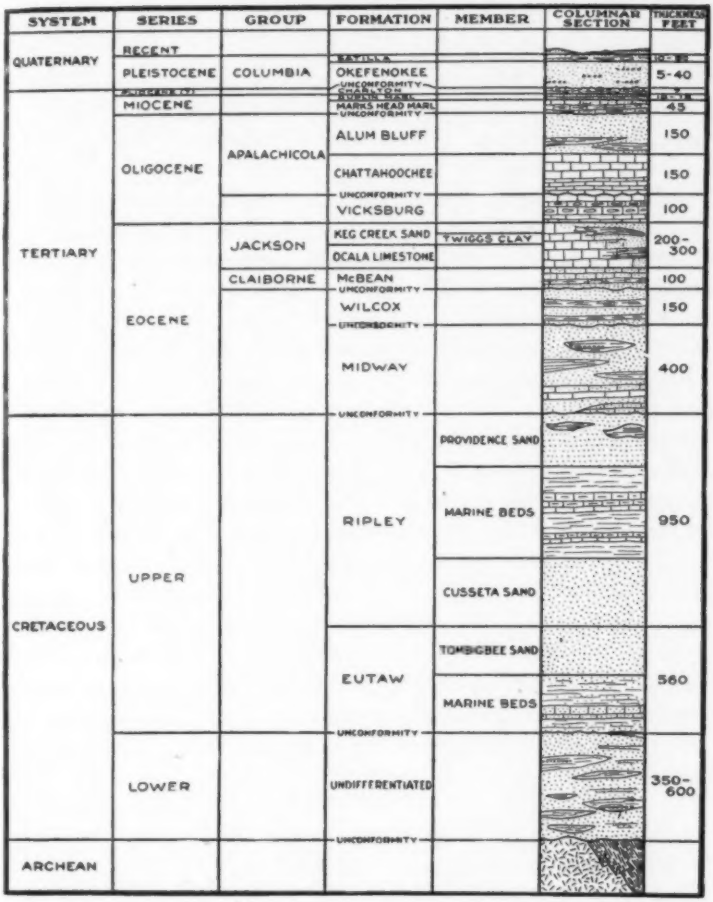

FIG. 4

EOCENE SERIES

The *Midway formation*, which forms the base of the Eocene series, lies unconformably upon the upper member of the Cretaceous and is unconformably overlain by the Wilcox. It consists of sand, clay, and marl, and forms a narrow northeast-southwest belt extending from Fort Gaines on Chattahoochee River to a point a short distance east of Flint River in Houston County. At no place does it exceed twelve miles in width.

The *Wilcox formation* has a distribution similar to the Midway, though it probably does not extend beyond Flint River. It is made up mainly of sandy, glauconitic shell marl and laminated, sandy, dark-colored lignitic clay. Near Flint River pure beds of white clay occur, with red and varicolored sand.

The *McBean formation* forms an extremely irregular belt which varies from two to thirty miles or more in width and extends entirely across the state. East of Ocmulgee River it rests unconformably on the strata of Lower Cretaceous age, while between Flint and Chattahoochee rivers it rests unconformably upon the Wilcox formation. It consists of shell marl, sandy limestone, glauconitic, calcareous sands, and clays in the form of fuller's earth.

The *Ocala limestone*, which is best developed between Ocmulgee and Chattahoochee rivers, is the main representative of the Jackson group in Georgia. Its eastern boundary lies usually a few miles west of Flint River, whence it extends south and west as a broad belt to the Georgia-Alabama-Florida state line, with an average width of more than thirty-five miles. The formation, as the name suggests, is made up of limestone with more or less chert in places.

OLIGOCENE SERIES

The *Oligocene series* is represented by the Vicksburg, the Chattahoochee, and the Alum Bluff formations, subdivisions of the Appalachicola group. The three formations are confined largely to the southern part of the Coastal Plain near the Georgia-Florida state line and to irregular areas southeast and southwest of Macon. The Vicksburg and the Chattahoochee formations, which are separated by an unconformity, consist largely of limestone, while the Alum Bluff formation is made up mainly of sands and clays.

MIOCENE SERIES

The *Marks Head Marl* and the *Duplin marl* are the only formations belonging to the Miocene series. These two formations, which are best developed at Porters Landing on Savannah River, consist mainly of marls, sands, and clays. The Marks Head marl unconformably overlies the Alum Bluff formation.

PLIOCENE SERIES

The *Charlton formation*, which is supposed to belong to the Pliocene series, occurs along St. Marys and Satilla rivers in the extreme southern part of the state. The formation consists mainly of shell marls.

The *Altamaha (Lafayette?) formation*, not shown in the columnar section, has the greatest areal extent of any formation in the Coastal Plain, covering approximately 21,000 square miles. Like the underlying Charlton formation, it is supposed to be Pliocene. The formation has a maximum thickness of less than three hundred feet and consists chiefly of sand, gravel, and clay, which in places become indurated. With the exception of a few fragments of wood it is entirely free from organic remains.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The Pleistocene is represented by the Okefenokee and the Satilla formations, divisions of the Columbia group. These formations form a belt along the Atlantic Coast, with a width from twenty to fifty miles. The Okefenokee consists chiefly of gray sand, and the Satilla is made up of greenish and bluish marine clays and gray and yellow sands.

SOME STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE PRE-CAMBRIAN OF NORTHERN QUEBEC

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PART II

DETAILED AREAL DESCRIPTIONS

In the following descriptions the structures of the separate areas studied will be briefly stated, with the conclusions as to succession which were made in each area. Fig. 3 shows the relative positions of the areas described. In the Opawika, Father's Lake, Windy Lake, and Eau Jaune–Obatogamau areas, where the rocks are largely of the basal lava series, or Abitibi volcanics, the determinations of the structure were in each case the result of a large number of observations, using the methods described, on the attitude of the lava flows over as wide an area as the nature of the work permitted. The results of each determination by any one of the methods described were checked whenever possible by the application of one or more of the other criteria as well. No other stratigraphic methods were applied or, in fact, were applicable. For the sake of brevity, therefore, the methods of determination of the structure in the separate instances will not be stated, as this would only involve unnecessary repetition.

The Opawika area.—The Opawika area (Fig.4) borders the Opawika River near its junction with the Waswanipi River. It includes the northern portion of Tush Lake, Opawika Lake, and the Opawika River from Opawika Lake down to Sturgeon fall. The rocks are a series of closely folded lavas and tuffs and are unusually well exposed. The axes of the folds strike N. 75° E., but their plunge was not determined. The approximate position of these axes is shown on the map. The southernmost fold, on Tush Lake, is an anticline, the southern limb of which is cut off by granite. The axis of the syncline to the north follows approximately the

south shore of Opawika Lake. The west end of the lake breaks across into the next anticline to the north.

The rocks in the southern anticline are andesites, fairly massive and without pillow structures. Dips vary from 65° to 90°. On the north side of this anticline, in the long east bay of Tush Lake, coarse

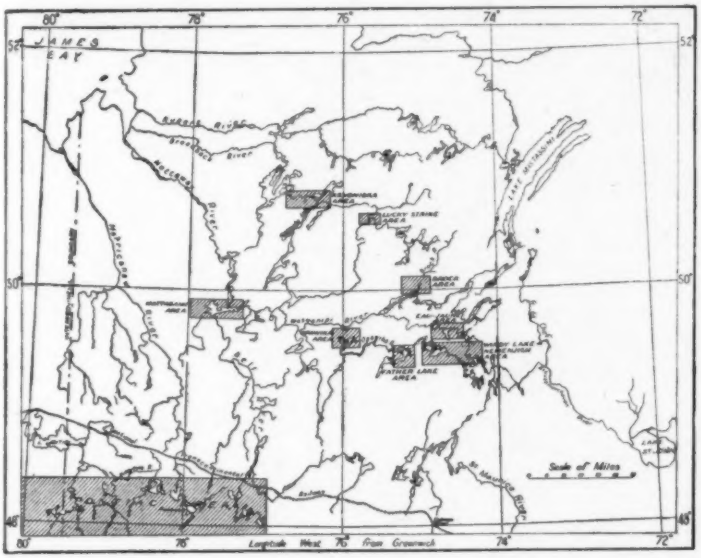

FIG. 3.—Key map of the part of northern Quebec dealt with in this paper, and the positions of the small areas particularly described.

andesitic tuffs lie conformably on the andesites. They are not bedded.

Along the axis of the syncline, on the south shore of the western end of Opawika Lake, a flow of highly acid quartz porphyry, a translucent, greenish-white rock, conformably overlies the andesite. In the anticline to the north, lavas of acidity intermediate between the quartz porphyry and the andesite outcrop until the normal andesite is again reached. The latter continues to outcrop as far as Sturgeon fall.

The succession in this area is:

Rhyolite porphyry lavas
Intermediate lavas
Andesites and andesite tuffs at or near the top of the flows

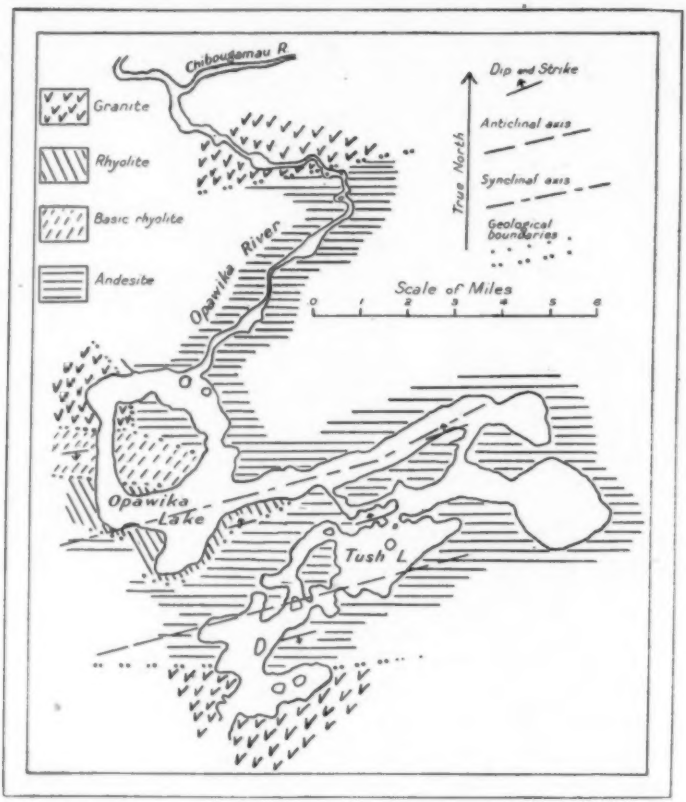

FIG. 4.—The Opawika area

It seems possible that the structure of this whole belt is that of a synclinorium, as the uppermost beds are found only near the the median line of the belt. However, this distribution may equally well be due to irregularity of original deposition, more especially as

the rhyolite lava was probably viscous and did not spread out far from its vent.

Father's Lake area.—The structure of this small area appears to be that of a synclinal drag fold, although the lack of outcrops on the northwest side of the lake makes its complete determination uncertain (Fig. 5). The flows around the southern border of the area

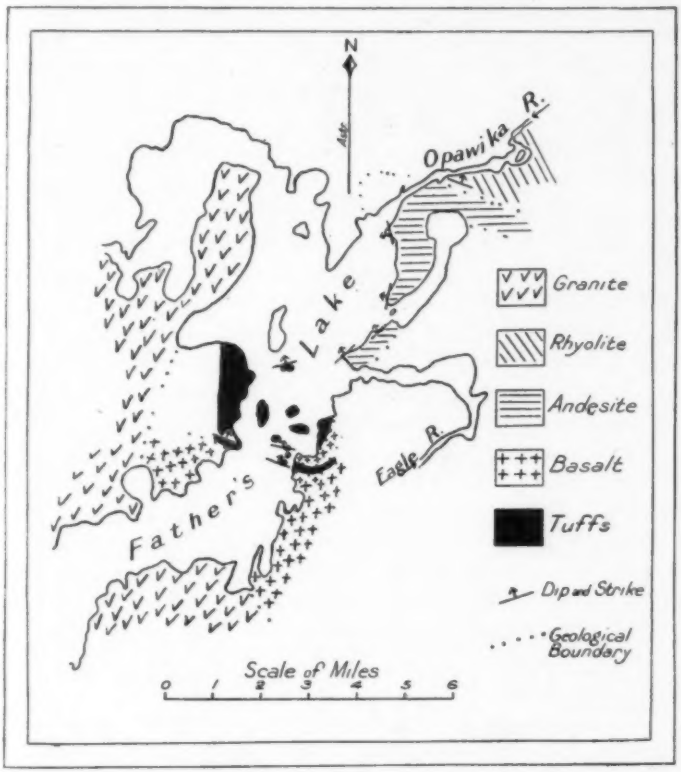

FIG. 5.—The Father's Lake area

are basaltic in composition and quite thin, some of them less than ten feet in thickness. Above them lie one or two flows of porphyritic basalt, characterized by feldspar phenocrysts up to one-half

inch in diameter. Beds of basic sediments overlie conformably the porphyritic basalts and in one place are interbedded with them. The beds approximate one inch in thickness, and the thickness remains uniform over the outcrops, which in some cases were exposed two hundred feet or more along the strike. The sediments are of tuffaceous composition and vary from grayish or reddish cherty rock, which may be in part a deposit from silica-bearing solutions accompanying the lava flows, to black hornblendic material, probably recrystallized volcanic dust. In places they are filled with lenses of gabbroid material averaging about four inches in length by one-quarter inch in width.

North of the mouth of the east bay into which the Eagle River empties, outcrops of andesite occur, with a northeast strike and a dip to the northwest. The strike swings gradually to the north, then to the east at the mouth of the Opawika River, where they are overlain by rhyolite. It is doubtful what relation the andesites bear to the basalts and sediments. The mapping as it stands leads to the inference that faulting of some magnitude has taken place along the east bay into which Eagle River empties, but it is impossible to prove this, as the rocks here are all heavily drift covered. The map, however, is a rather inferior grade of track survey, and the impression gained in the field by assuming a projection along the strike was that the andesites overlie the basalts and part of the sediments and underlie the remainder of the sediments.

It may be observed that the basaltic flows in this area have no ellipsoidal textures, while the andesites are ellipsoidal. The significance of the fact will be discussed in a subsequent section. The succession in the Father's Lake area is

Rhyolite	Tuffaceous sediments
Andesite	Porphyritic basalts
	Basalts

Windy Lake–Nemenjish area.—The structure of the Windy Lake–Nemenjish (Fig. 6) area is monoclinal, so far as known, with a general east-west strike and a southward dip. This structure has been attained by strike faulting, with consequent repetition of outcrops. One large fault, whose south side was upthrown, was observed on Windy Lake, and possibly others occur to the south

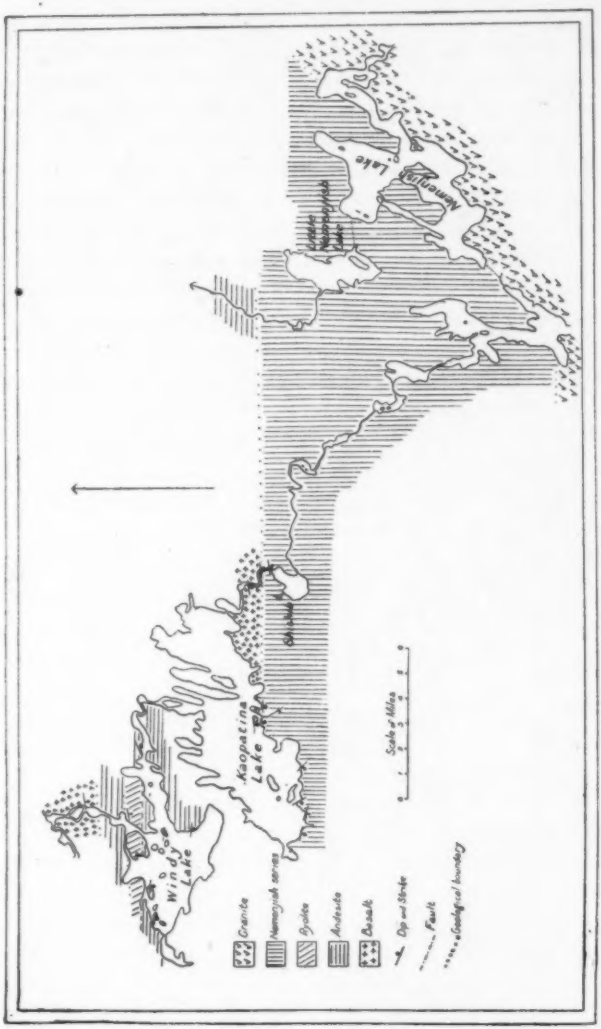

FIG. 6.—The Windy Lake–Nemenjish area

on Kaopatina Lake where most of the outcrops are hidden by a heavy cover of drift. The plunge of the folding appears to have been to the east, for near the west end of the area the strikes assume more of a north-south trend, which may indicate the presence of the axis of a cross-fold near-by, though it may be due merely to the subsequent disturbing influence of the granite intrusion to the west.

The basal rocks of the series, found on the river above Bras Coupe Lake, are very basic basalts, one flow of which is unusually fresh and glassy. These, like the basal flows on Father's Lake, possess no ellipsoidal structures. They are overlain to the south, as far as the outlet of Windy Lake, by andesites characterized by good pillow structures. A thin body of somewhat more acid lava lies above the andesites, and on this is found a bed of coarsely fragmental rhyolite, approximately 2,000 feet thick. Its composition is identical with that of the massive rhyolite porphyry on Opawika Lake. This fragmental rock shows no trace of bedding, as would a water-laid sediment, although we may conclude from the evidence of the pillow structure in the underlying andesites that the sea or a lake existed here at the time. It seems necessary to conclude therefore that the rock was not ejected as a tuff, but as a lava, and that its present fragmental condition is due to subaqueous extrusion, and hence corresponds to the pillow structure in the more basic lavas. Corroborative of this conclusion, rhyolite porphyry in the same fragmental condition was also found on Obatogamau Lake, where it rests directly on well-bedded tuffs, thus again indicating its subaqueous extrusion.

The southern boundary of the fragmental rhyolite is a fault, to the south of which the ellipsoidal andesites again outcrop.

Between the south shore of Windy Lake and the south shore of Kaopatina Lake the structure is unknown, as outcrops are not numerous or large enough for its determination, although there are sufficient to indicate that the formation is continuous across the gap. However, since the outcrops on the south side of Kaopatina Lake are of the basalts of the series, which elsewhere always occupy a basal position, and since they still maintain an east-west strike and a dip to the south, the intervening drift-covered gap must be supposed to be underlain by the south limb of a syncline whose

north limb is found on Windy Lake, and by the crest of the next anticline; or else it must be assumed that another strike fault again upthrows the lower beds on the south.

The determination of the attitude of the beds on the south side of Kaopatina Lake, the correctness of which is a matter of great importance, was made with the greatest care in three different places, in each case by tracing a flow from its coarse-grained base up to its fine-grained top, where it was found in contact with the coarse-grained base of another flow. Lying above these basalts, and conformable on them, is a thick series of thin-bedded tuffs, interbedded with which, and rather high up in the series, is a thin flow of rhyolite porphyry. This flow is of small areal extent and appears only in the west end of the lake.

On the Opawika River above Kaopatina Lake the same relations were observed. Rather thick flows of basalt with a strike of N. 80° E. and a dip of 80° south are here conformably overlain by thin-bedded, rather basic tuffs. The plane of contact is occupied by a dyke of granite, which appears to be an offshoot of a larger mass to the east, as the dyke was not observed along the contact farther to the west, and where observed widens rapidly toward the east. The strike and dip of the tuffs is identical with that of the underlying basalt. About thirty feet above the contact a basalt flow about four feet in thickness is interbedded with the tuffs.

Passing higher into the tuffs toward the south, it was observed that the beds of tuff begin to be mingled with beds of metamorphosed clastic sediment. The latter become more numerous and finally replace the tuffaceous beds completely. At the same time the thickness of the separate beds increases until on the south side of Lake Shishib the beds are so heavy and massive that a bedding plane can rarely be observed.

The thick-bedded rocks on Lake Shishib are garnetiferous mica gneisses, probably recrystallized impure sandstones, or sandy shales. They continue to outcrop at intervals up the Opawika River to Dinachagama Lake, where they begin to be intruded by granite masses. They were traced across the Height of Land into Lake Nemenjish, on the north shore of which the sediments are well exposed and comparatively undisturbed by granite intrusion. Here

the mica gneiss is interbedded with garnetiferous mica gneiss, hornblende gneiss, or amphibolite, garnetiferous hornblende gneiss, and crystalline limestone. The garnetiferous mica gneiss is identical in composition with the non-garnetiferous type, except for the presence of the garnets. The hornblende gneiss, or amphibolite, is a black, gabbroid rock, which may be of igneous origin, although no evidence of such origin could be obtained, and it is interbedded with the other rocks with perfect conformity. The garnetiferous hornblende gneiss is very similar to the non-garnetiferous type, with the addition of garnets; as in the case of the other, no evidence of an igneous origin could be obtained for it, and it is suspected that it may be a recrystallized, impure, calcareous sediment. In support of this view is the fact that the only crystalline limestone found, consisting of two beds, each about a foot in thickness, is interbedded with the garnetiferous hornblende gneisses.

This series of sediments has been named by the writer the Nemenjish series, from the lake on which it is best exposed.

The succession in these areas is therefore as follows:

Windy Lake Area	Kaopatina-Nemenjish Area
Tuffaceous sediments	Nemenjish series: Interbedded garnetiferous and non-garnetiferous mica gneisses and hornblende gneisses, with crystalline limestones
Rhyolite porphyry	Garnetiferous mica gneisses
Flows of intermediate composition	Interbedded mica gneisses and basic tuffaceous sediments
Andesites	
Basalts	Basalts

Eau Jaune–Obatogamau area.—This area includes Eau Jaune Lake and part of Obatogamau Lake (Fig. 7), together with a part of Presqu'ile Lake; but outcrops below Eau Jaune Lake are so scarce that the structure of this latter portion of the area could not be determined. The area is of interest mainly because of its conspicuous cross-folding. In the other areas described the axes of folding have a general east-west strike, and the cross-folding has been sufficient only to give these axes plunges varying from 15° to 30°. In the Eau Jaune area and, it may also be remarked, in the sediments on Nemenjish Lake, the cross-folding is as intense

or more so than the folding along east-west axes. As these are the most easterly areas studied, it is not known whether the cross-folding represents merely a local crumpling along some plane of weakness or whether the areas are on the western edge of a region folded along northeast and southwest axes. A study of the reports and maps of the country to the east and north, however, makes the latter supposition seem probable.

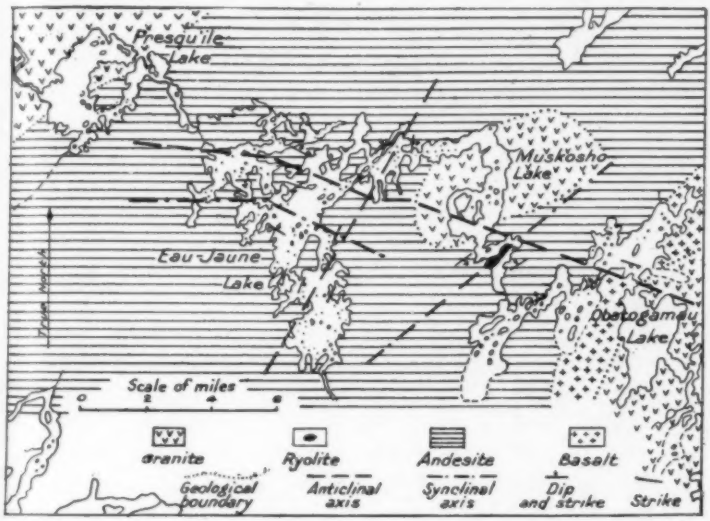

FIG. 7.—The Eau Jaune–Obatogamau area

The position and direction of the axes of folding are shown on the map. The one set, corresponding with those in the other areas described, strikes S. 70° E., apparently swinging in the western part of the area to east. The other set strikes N. 35° E. on Eau Jaune Lake, and N. 50° E. on Obatogamau Lake. The succession and distribution of beds suggest that the larger structure is that of a synclinorium whose axis has a northeasterly strike. The rocks on the eastern side of the area are basalts. Andesites overlie the basalts on the eastern side and outcrop also in the western part. Their composition gradually becomes more acid toward the center,

and along the central synclinal axis there lies a small area of basic tuffs, overlain by twenty to thirty feet of fragmental rhyolite porphyry. The succession was well determined, and the distribution would indicate conclusively a general synclinal structure were it not suspected, as in the Opawika area, that the rhyolites are localized in their original distribution.

The best determinations of structure were made on the western part of Obatogamau Lake and the eastern part of Eau Jaune Lake, where the presence of large and easily determinable ellipsoidal structures rendered work easy. Time did not permit of the intensive work necessary for the determination of the structures of the basalts in the northern and eastern parts of Obatogamau Lake, while outcrops are rare along the eastern shores of Eau Jaune Lake.

The basalts of Obatogamau Lake are characterized by ellipsoidal structures, in contrast with the basalts of the areas to the west. The ellipsoidal structures in the basalts are small and difficult of recognition, except on unusually clean surfaces, so that they do not aid greatly in the determination of the attitudes of the flows. If this structure is an indication of submarine extrusion, however, their occurrence at this point will indicate that the seashore at the time of the basaltic extrusion lay between Obatogamau and Kaopatina lakes. From this point it must have transgressed rapidly westward as extrusion proceeded.

The succession as determined in this area is:

Rhyolite porphyry, fragmental	Andesite flows
Andesite tuffs	Basalt flows

Brock area.—The Brock area (Fig. 8) is situated at the confluence of the Brock and Chibougamau rivers. Unfortunately outcrops are poor in this locality on account of the cover of stratified sands extending up the Chibougamau valley.

The basal rocks are a series of basic lavas which are here more schistose than those farther to the south, presumably because of the shear between them and the overlying formation at the time of folding. Their structure was not determined. To the north of these is a series of sediments, which were found to form the south limb of a syncline, the north limb of which has been cut off by granite. At the southern contact of the series lies a heavy band

of conglomerate. Only one outcrop of this was seen, about a mile below the mouth of the Brock River. At this point the conglomerate is very schistose. The pebbles are so numerous as almost to exclude matrix, which is a rather impure sand. About 30 per cent of the pebbles are hornblende granite; the remainder are various basic rocks, now so sheared that their original composition is indeterminable, although it is clear that they are of several kinds. The stresses to which the rock has been subjected have deformed the pebbles according to their original hardness. The softer have been

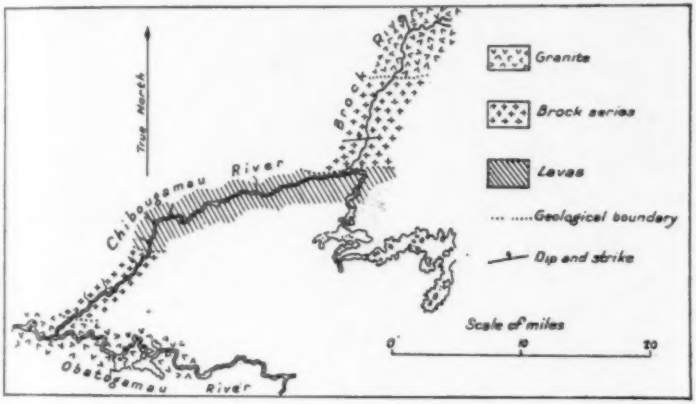

FIG. 8.—The Brock area

converted into narrow strings several inches in length by a fraction of an inch in width; harder ones have been flattened into lenses the shape of which depends on the original hardness; while those of granite, the most resistant, have been deformed by fracture rather than by flow, and still retain much of their original shape. The softer pebbles have flowed around the harder, accommodating themselves most closely to all their curves. Fig. 9 illustrates this conglomerate. The almost undeformed granite pebbles are well shown; in some cases even the fractures in them, inclined at about 45° to the planes of schistosity, may be seen. Some of the more prominent pebbles of softer materials are also clearly visible, with the manner in which they have flowed around the harder granites.

The rocks directly overlying the conglomerate are drift-hidden, but the next outcrops to the north are of mica gneiss and hornblende gneiss, which probably represent the recrystallized product of sandy shales. To the north of this, beds of altered impure sandstone and grit are found, beyond which mica and hornblende gneisses again appear. The latter rocks continue to outcrop to the northern limit of the area, where they are intruded and cut off by granite.

FIG. 9.—Conglomerate about a mile below the mouth of the Brock River

The rocks of the area were determined from observations on a number of drag folds, to form the south limb of a syncline or the north limb of an anticline. The axial planes of secondary drag folds were observed to dip toward the north. Hence the folding is of the abnormal type. The axes of these drag folds plunge, where observed on the Brock River, about 22° to the west. Hence the plunge of the primary fold at this point is to the west. The general strike of the axes of these drag folds is N. 80° to 85° E.

About twenty-five miles down the Chibougamau River, near the mouth of the Opawika, another wide area of rocks similar to the upper beds of this series of sediments outcrops. The basal conglomerate, however, was not found here, so that it is possible that

these beds may not belong to this series, but may be fine-grained sediments of the Nemenjish series. The beds dip toward the north, but a consideration of the relative movement of the beds inferred from the shape of the drag folds showed that they form the south limb of an overturned anticline. It seems possible therefore that these beds are the south limb of the anticline of which the Brock sediments form the north limb. If so, the axial plane of this large fold dips to the north.

The succession in the Brock area therefore in order of age appears to be:

Mica and hornblende schists
Grits
Conglomerate
Uncomformity
Green schists and basalts

Lucky Strike area.—The Lucky Strike area (Fig. 10) lies at and above the junction of Lucky Strike creek with the south branch of the Broadback River. Here, as in the Brock area, the youngest rocks are granites, which intrude a series of sediments, consisting of conglomerate at the base, passing upward into arkose or greywacke, and then into muscovite schists which probably represent impure sandstone. Beds which may have overlain these have been cut off by the granite. All the beds are much deformed, although not so much as in the Brock area. The following pebbles were observed in the conglomerate: hornblende granite, quartz biotite schist, anorthosite (one only), hornblende schist, made up almost wholly of hornblende needles; hornblende schist containing 30 to 40 per cent plagioclase, quartz porphyry, bedded chert, and others which were originally of softer rock and are now so deformed as to render their original nature indeterminable. Many of these pebbles are recognizable as having been derived from the lava series, so that the conglomerate is evidently unconformable above it. The harder pebbles have suffered little or no deformation and are well rounded, indicating long attrition before deposition in their present position.

The older series is not well exposed in this locality. Directly underlying the conglomerate in one place is found a garnetiferous

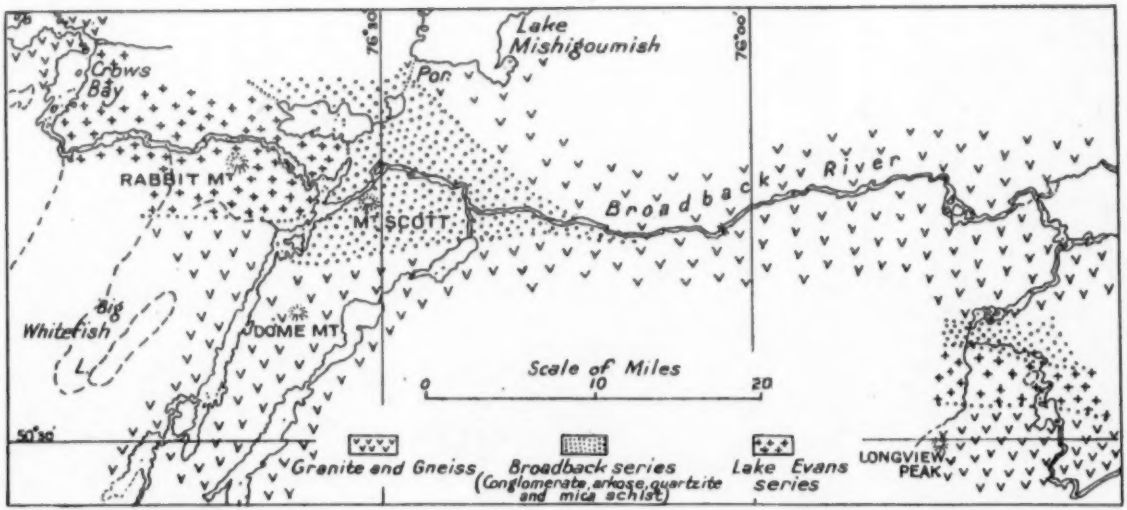

FIG. 10.—The Kenoniska area (about Mount Scott) and Lucky Strike area (north of Longview peak)

mica gneiss, identical in composition with the corresponding garnetiferous gneiss of the Nemenjish series on the Opawika River. Below this, in scattered outcrops, were observed basalts, basic intrusives, tuffs, and carbonate schists.

The succession in this area is therefore:

Broadback series, sandstone, now muscovite schist, arkose or greywacke, conglomerate

Unconformity

Nemenjish series, garnetiferous mica gneiss

Basic intrusives, basalts, tuffs, carbonate schists

Kenoniska area.—This area (Fig. 10) lies at the north end of Kenoniska Lake, on the Broadback River. It was mapped in part during the work of 1912. The map published at that time included the results of information gained by an earlier observer, which re-examination by the writer in 1914 proved to have been incorrect. As a result the formation boundaries shown on the map of 1912 are not to be accepted as final.

The geologic section in this area is very similar to that found in the Lucky Strike area, but is of more value, partly because the section is better exposed and more complete, and partly because undeformed rocks are to be found. The structure of the area is that of an anticline about ten miles in width, both limbs of which are cut off by granite. The anticline plunges to the east. The rocks on the limbs are very much sheared, but at the crest of the anticline, which is seen about five miles above Kenoniska Lake, the shearing has been so slight that even the slightest foliation can barely be detected.

The uppermost series, which was termed the Broadback series by the writer in 1912, consists of sediments which lie unconformably on an older series consisting mainly of lavas. At the base of the sedimentary series there are two heavy bands of conglomerate, separated by a thick band of fine-grained greywacke containing occasional pebbles. Above the conglomerate occur in order arkose, a thin band of quartzite, and mica schist. The latter includes both muscovite and biotite schists, of which the biotite schists are the larger in amount. The muscovite schists are probably the metamorphosed equivalent of very siliceous shales, the biotite schists of less siliceous shales.

The conglomerate on the limbs of the fold has been so sheared as to deform all the pebbles, as in the case of the conglomerate described in the Brock area. At the nose of the anticline, however, the rock is undeformed. The number of pebbles is so great that very little of the greywacke matrix is observable. The majority are unusually well rounded and of all sizes, up to eight inches in diameter. The material is very poorly assorted and markedly cross-bedded. The variety of the pebbles is great. About 50 per cent of the total number are of light-colored biotite granite; a few, about 4 or 5 per cent, of a still more siliceous granite, with almost no ferromagnesian mineral; 10 to 15 per cent consist of dark, bluish chert, often banded; while the remaining 30 per cent are quartz and various basic rocks, hornblende schist, andesite, etc., most of which can be matched in the lavas below.

The underlying series, which was named the Lake Evans series in 1912 consists near the base of basalts overlain by porphyritic andesites. Some thin-bedded, fine-grained, slaty tuffs were found overlying the andesites on Storm Lake; probably overlying these tuffs, and directly underlying the Broadback conglomerate, are some thin beds of garnetiferous mica gneiss, petrographically similar to certain of the members of the Nemenjish series. The structure of these rocks could not be worked out in detail on account of lack of outcrops, but the strike and dip of the bedding, wherever observable, is approximately parallel to the bedding of the overlying Broadback sediments.

As already stated, the general structure of this area is that of an anticline, whose axis has a strike of S. 75° E., and a low plunge to the east. If the axis of this fold be projected eastward across the intervening granite area, it is found to pass through the Lucky Strike area; so that these two areas probably form the two limbs of a large synclinal cross-fold, whose axis strikes N. 15° E. If so, the plunge of the Lucky Strike anticline, which was not determined in the field, must be toward the west.

The succession in the Kenoniska area therefore is:

Mica schist	Nemenjish series (?) garnetiferous mica schist
Quartzite	
Arkose	Slaty tuffs
Conglomerate	Andesites
Unconformity	Basalts

Mattagami area.—This area (Fig. 11), which lies on Mattagami Lake, has been briefly examined by the writer, but has been studied in detail by J. A. Bancroft.[1] The following is a summarized description of the more important points of composition and structure described by him.

The rocks include, as in the three foregoing areas, an overlying sedimentary and an older lava series. The sediments have been named by Bancroft the Mattagami series. They form a belt underlying the bed of the lake which outcrops at intervals along its shores over a distance of about fifteen miles. They consist almost wholly

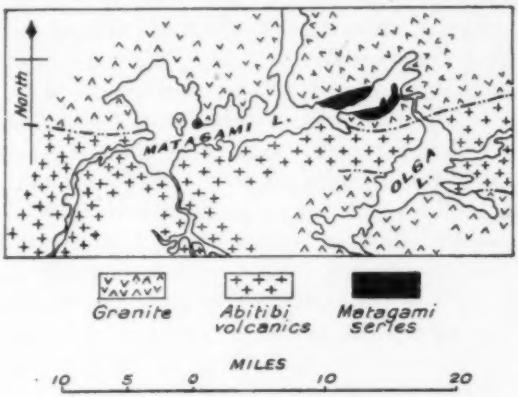

FIG. 11.—The Mattagami area

of quartz biotite schists, which are probably the metamorphosed equivalent of impure sandstones; these pass into conglomerate in places by the addition of pebbles of all sizes up to six inches in diameter. The pebbles are always scattered, never crowded together as in the conglomerates already described. However, it may be that if the series were better exposed bands of the more characteristic conglomerate would be seen. The deformation has been so great that all the pebbles with the exception of the hard granites have been squeezed, flattened, and in many cases reduced to narrow strings; while even the granites have been much granulated and recrystallized. On this account the recognition of the

[1] *Report on Mining Operations*, Quebec, Department of Colonization, Mines, and Fisheries, 1912, p. 131.

original nature of the pebbles is difficult. About 60 to 70 per cent of them are of granite; the remainder includes diorite, aplites, and biotite and hornblende schists.

Bancroft considers these sediments as probably unconformable on the series of lavas that lies to the south. The structure is difficult to determine, as the granite intrusions have cut off the sediments to the north, and have stoped their way to the lavas. Bancroft is of the opinion that the structure is that of a tight syncline; however, it appears equally probable that the present band represents only the south limb of a syncline, whose north limb has been cut off by granite. The writer inclines to the belief that the structure of the whole belt between Mattagami Lake and the National Transcontinental Railway is a great anticlinorium, the Mattagami series of sediments representing the north limb, the sediments of the Pontiac series the south limb. This theory, however, is unsupported by facts other than the petrographic resemblance of the sediments of these two groups and a general parallelism in their strike. It can probably never be proved by field evidence, as outcrops over the intervening territory are too small and scattered to make any continuous determination of structure.

To the south of the Mattagami series lie the supposedly older rocks, consisting of lavas, intrusives, and tuffs. The lavas include andesites and basalts principally, some of them distinguished by beautiful ellipsoidal structures. Slaty tuffs were observed in a few places. The strike of these rocks, where observed, is in general east-west, like that of the overlying sediments. The most important intrusive in the vicinity of Mattagami Lake is a large body of very coarse, feldspathic gabbro, petrographically identical with the gabbros which in other localities have been observed to grade into anorthosites, and probably to be correlated with them. It intrudes the lava series, but does not ascend as high as the contact with the sedimentary series; hence its relation to the sedimentary series is indefinite.

The succession in the Mattagami area therefore appears to be:

Mica schists	Basic intrusives
Conglomerate	Basalts, andesites, rhyolites, and tuffs
Uncomformity	

Pontiac area.—The Pontiac area (Fig. 12) lies far to the south of the Brock, Broadback, and Mattagami areas but its rocks are strikingly similar. It is found to the south of the National Transcontinental Railway with its western end close to the Ontario-Quebec boundary; it is nearly one hundred miles in length by twelve in breadth. The rocks have been studied by M. E. Wilson[1] and J. A. Bancroft.[2] The following is a summarized account of their descriptions.

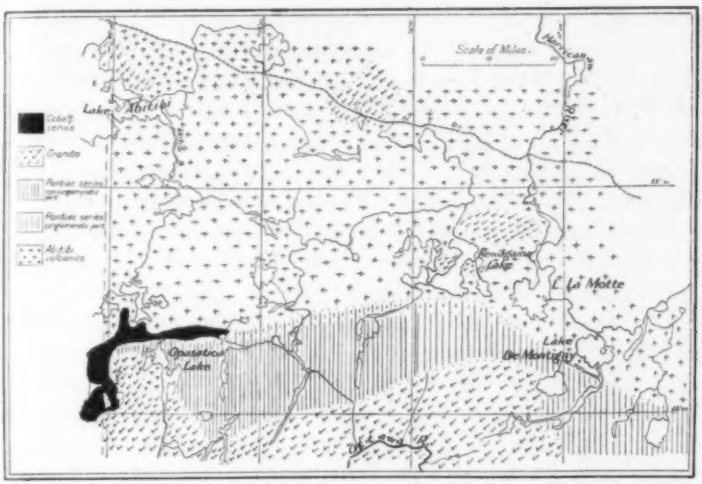

FIG. 12.—The Pontiac area

The rocks of the region fall into two general classes, a volcanic complex and a series of metamorphosed clastic sediments, termed by Wilson the Pontiac series. The Pontiac series is cut off on the south by intrusions of granite; the volcanic complex lies to the north of it. The band of sediments averages ten miles in width; the major part of this, about nine miles, is underlain by mica schist, with which is associated some hornblende schist and amphibolite.

[1] *Geol. Surv. Can.*, Mem. No. 39, 1914.

[2] *Report on Mining Operations for 1911*, Department of Colonization, Mines, and Fisheries, Quebec, p. 160; 1912, p. 199.

Toward the northern edge mashed arkose, greywacke, and conglomerate are found. The mica schist is a fine-grained rock consisting essentially of quartz and biotite usually with some feldspar. The arkose and greywacke are of much the same composition, though coarser in grain; they differ from each other only in the relative proportions of acid and basic fragments they contain. Both pass into conglomerate by the gradual addition of pebbles.

The composition of the conglomerate apparently varies a great deal from place to place. Wilson states that in the more western portions of the area studied by him he found pebbles only of granite, rhyolite, and quartz porphyry and none of the more basic rocks. Bancroft, on the contrary, working in the more eastern parts of the area, reports the majority of the pebbles to be of greenstone, although pebbles of granite and diorite are not uncommon. Metamorphism has squeezed and flattened all the pebbles more or less, converting the softer of them often into mere strings.

The Pontiac series overlies the volcanic complex unconformably according to Bancroft, as most of the pebbles of the conglomerate can be matched in the rocks below. Wilson, who did not find outcrops containing the more basic pebbles, doubts the uncomformity and is inclined to believe that the sedimentary series is older than the volcanic, since the general dip is steeply to the north. To secure further evidence, if possible, on this question in dispute, the writer visited Lake de Montigny in 1917 to examine the contact there. The contact itself has been exposed here in workings of some prospectors, and the lavas to the north are well exposed. The examination by the methods outlined in the beginning of this paper indicated that the south side of the flows is the uppermost. This evidence therefore confirms Bancroft's conclusion that the sediments overlie the flows, and some further support to it is given by the similarity of the Pontiac series to the Brock and Broadback series, both of which are undoubtedly younger than the volcanics. The northward dip must be ascribed to overturned folding.

The general trend of the strike of these rocks is east-west, and the dip, as stated, steeply north. Bancroft is inclined to believe that they form a tight syncline, but against this hypothesis lies the

fact that the conglomerate member is found only on the north side of the band of sediments. It seems more probable that they form the north limb of a syncline, whose south limb has been stoped off by the granite, while its anticlinal continuation to the north has been removed by erosion. If this is the case, the axial plane of this syncline must dip to the north.

Both Wilson and Bancroft have described all the sediments as parts of one sedimentary series. Since their work was published, however, several facts have come to light which are difficult of explanation if the rocks are to be considered as a single series, while the fact that outcrops are exceedingly poor in this district, owing to the heavy cover of glacial lake clays, renders it possible that two or more series of metamorphosed sediments have been inadvertently grouped together. The facts which tend to throw doubt on their interpretations are:

1. On Lake de Montigny, at the contact of the Pontiac series and the underlying greenstones, no conglomerate is found. The basal beds of the sedimentaries are dark mud rocks of the composition of a basic greywacke. Conglomerate does not occur here. Wilson describes the conglomerate as occurring in discontinuous patches. In the series of younger sediments to the north, already described by the writer, the conglomerate band at the base of the younger sedimentary series is always thick, strong, and continuous.

2. Wilson describes amphibolites occurring interbedded with the mica schists of the Pontiac series in places. Amphibolites were not observed by the writer to form part of any of the younger sedimentary series in any of the areas studied by him; they are, however, very characteristic of the Nemenjish series and form a considerable proportion of it.

3. Wilson[1] found outliers of the Grenville series (which, it will be shown, is probably correlative with the Nemenjish series) on Grand Lake Victoria, about twenty-five miles south of the most eastern outcrop of the Pontiac series. Bancroft[2] in 1916 found outliers of the Grenville series as far west as Doucet, some thirty miles

[1] *Geol. Surv. Can., Sum. Rept.*, 1912, p. 337.

[2] Personal communication

east of the most eastern outcrop of the Pontiac series. The intervening distance has not been closely examined. It seems strange that the Grenville series should approach the Pontiac so closely and yet not be found within the Pontiac area, and that so widespread a series as the Pontiac should end so sharply, and no further trace of it be found included in the granites to the south or east. Both these difficulties would at once disappear, however, if at least a part of the Pontiac were identical with the Grenville series.

4. To the north of the main belt of the Pontiac series Wilson has mapped several minor areas of sediments surrounded by the Abitibi volcanics. They are of mica schist only, without the conglomerate member. If the conglomerate and all the mica schists form a part of the same series, the conglomerate member should appear in these areas also, along the line of contact of the greenstones and the sediments.

In view of these facts the writer tentatively advances the view, alternative to that suggested by Wilson and Bancroft, that the so-called Pontiac series consists of two sedimentary series. The older, composed mainly of mica schists and amphibolites, is equivalent to the Grenville and Nemenjish series and may lie upon the older volcanic series conformably. The younger contains the conglomerate, arkose, and greywacke members, and perhaps a portion of the mica schists, and may be equivalent in age to the Mattagami, Broadback, Lucky Strike, and Brock series.

The rocks of the volcanic complex underlying the Pontiac series consist mainly of lavas varying in composition from basalt to rhyolite; the types of intermediate composition are the most common. Interbedded with them are small amounts of slate or slaty tuff, and dolomite, which in part at least is an altered rhyolite. Intrusive into these rocks are bodies of gabbro and diabase. All of the rocks have undergone more or less metamorphism and have been converted locally into schists. Outcrops throughout the area are too sparse to determine structure and succession, but wherever strikes are determinable they have a general east-west direction.

Summary.—The geological sections described in the foregoing areas may be summarized as follows:

Pontiac Area

Mica schist
Arkose, greywacke
Conglomerate
Unconformity
Basalt, andesite, rhyolite, tuffs, and intrusives

or

Mica schist
Arkose, greywacke
Conglomerate
Unconformity
Mica schist and amphibolite
Basalt, andesite, rhyolite tuffs, and intrusives

Matlagamie Area

Mica schists
Conglomerate
Uncomformity
Basic intrusives
Basalts, andesites
Basalts, andesites, rhyolites, tuffs

Kenoniska Area

Mica schists
Quartzite
Arkose
Conglomerate
Unconformity
Garnetiferous mica schists
Slaty tuffs
Andesites
Basalt

Lucky Strike Area

Mica schist
Arkose, greywacke
Conglomerate
Unconformity
Garnetiferous mica schist
Tuffs, basalts, basic intrusives

Brock Area

Mica and hornblende schists
Grits
Conglomerate
Unconformity
Basalts and schists

Windy Lake Area

Tuffaceous sediments
Rhyolite porphyry
Flows of intermediate composition
Andesite flows
Basalt flows

Kaopatina–Nemenjish Area

Interbedded garnetiferous and non-garnetiferous mica gneisses and hornblende gneisses, with crystalline limestones
Non-garnetiferous mica gnesises
Interbedded mica gneisses and basic tuffaceous sediments
Basalt flows

Eau Jaune–Obatogamau Area

Fragmental rhyolite
Andesite tuffs
Andesite flows
Basalt flows

Father's Lake Area

Basic tuffs
Andesite flows
Porphyritic basalt flows
Basalt flows

Opawika Area

Rhyolite flows
Intermediate lavas
Andesite tuffs
Andesite flows

[*To be continued*]

A CONNECTING LINK BETWEEN THE GEOLOGY OF THE NORTHERN SHAN STATES AND YUNNAN

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T. H. D. La Touche has described in detail the geology of the Northern Shan States west of the Salween River and up to latitude 23° north.[1] J. Coggin Brown has at one point extended this work farther north, having thoroughly mapped the section between longitudes 97° 00′ and 97° 30′ and extending north to latitude 23° 15′.[2] But beyond this area north to the border of Yunnan the ground has not been studied by the Geological Survey of India. North of the border in Yunnan the broader details of the geological structure have again been studied and mapped by J. Coggin Brown and made available in various survey reports.[3]

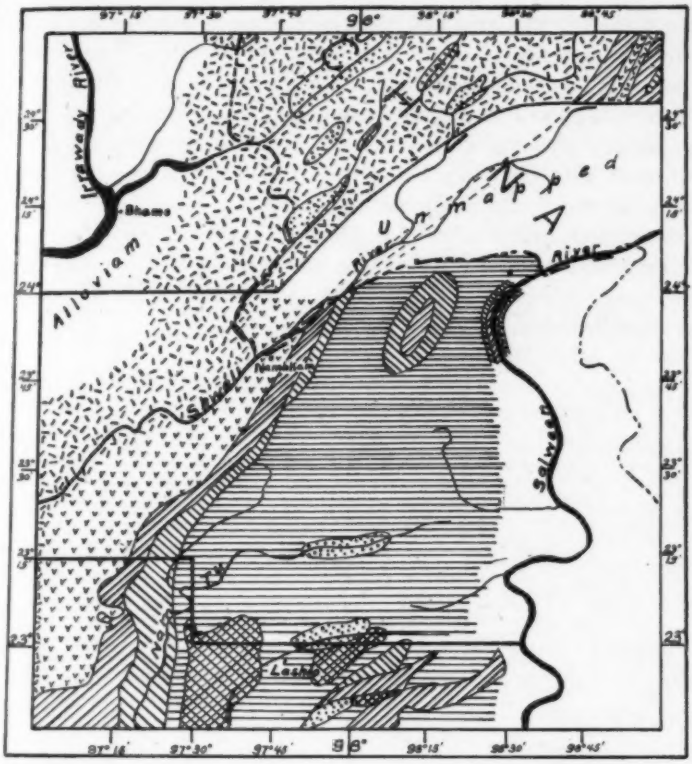
During the years 1917–18 the writer and several others, while doing exploration work for the Burma Mines, Limited, were enabled to take rough geological notes covering the unmapped area described above. By means of this work, as is shown on the accompanying map, the gap between the area in the South mapped by La Touche and Coggin Brown and that in Yunnan by Coggin Brown is partially filled in.

On the whole the section offers no points of marked difference from the areas to the south and north. Some slight differences between formations in Yunnan and the portions of the Northern Shan States familiar to him kept Coggin Brown from making definite

[1] T. H. D. La Touche, "Geology of the Northern Shan States, "*Memoirs of the Geol. Surv. of India*, XXXIX, Part 2.

[2] J. Coggin Brown, "Geology and Ore Deposits of the Bawdwin Mines," *Records, Geol. Surv. of India*, XLVIII, Part 3.

[3] J. Coggin Brown, "Contributions to the Geology of the Province of Yunnan in Western China: I, The Bhamo-Teng-Yueh Area," *Records, Geol. Surv. of India*, XLIII, Part 3, and other articles in the same series.



Geological map of a portion of the Northern Shan States Upper Burma and Yunnan

Scale - 20 miles to an inch

Archaean
Granite
Cambrian
Cambrian? Ordovician Silurian
Devonian Permo-Carboniferous Limestone
Jurassic
Tertiary
Yunnan-Burma Boundary

Mapped by India & S. Burma
Mapped by the writer
Key to map

correlations. The area described here helps to explain these differences and assists in correlating the two sections. Owing to the strictly economic purpose of our work in the field no attempt to gather fossils was made, and consequently the mapping was done on strictly lithological grounds. The various formations have, however, with the exception of the Ordovician and Silurian beds, such definite lithological characteristics that their determination can be safely made without recourse to fossils. The Ordovician-Silurian beds are not mapped separately but are shown as a single formation between the known older slates and quartzites and the younger Devonian-Carboniferous limestone.

TABLE I

LIST OF FORMATIONS

Period	Name in the Northern Shan States and Character	Yunnan Equivalent
Recent, Subrecent	Alluvium—old river terraces—travertine	Nan Tien series
Tertiary	Clays—sandrock and brown coal	
Jurassic	Nam Yau series—red sandstones with limestone beds	
Permian, Carboniferous, Devonian	Plateau limestone—not differentiated into an upper and lower as by La Touche because of lack of fossil evidence	Permo-Carboniferous and older Paleozoic limestones
Silurian, Ordovician	Namhsim, Naungkangyi, and other Silurian and Ordovician beds of La Touche grouped because of lack of fossil evidence, shales, sandstones, and some limestone beds	Pu-Piao series
Ordovician, Cambrian?	Pangyun beds—not mapped by La Touche. Sandstones, shales, and occasional limestone beds	Possible transition beds between Kao-liang and Pu-Piao
Cambrian	Chaung Magyi—quartzites and shales	Kao-liang series
Archean	Mogok gneiss with limestone bands	Crystalline series. Gneiss, granite and mica schist with a few limestone bands of Brown
Igneous	Granite—intrusive into gneiss and Chaung Magyi but age unknown. Basic dikes—intrusive into the granite	

In Table I are given the formations present in the area discussed. The same names are assigned to them as are used by La Touche in his *Geology of the Northern Shan States*. In the right-hand column are given what appear to be the corresponding formations in Yunnan. The names are those given by J. Coggin Brown in his reports on that province.

TOPOGRAPHY

The main structural features are the high mountain region of the western section (some of the peaks being over 7,000 ft.) composed of granite, gneiss, and the older Paleozoic sediments, and the

more open, less accentuated, topography of the Plateau limestone over most of the eastern section.

The Shweli in the North and the Nam Tu in the South both flowing in a general southwesterly direction are the dominant streams, carrying off all the drainage of the area, with the exception of a narrow strip along the eastern edge, where the streams flow east into the Salween. The Salween flows almost due south and, as is characteristic of it for most of its course through Yunnan and Burma, it has cut its way down far below the surrounding country and consequently has a very limited lateral drainage. The streams flowing into the Salween in this section have a length rarely exceeding thirty miles. Notwithstanding this fact it far exceeds any of the other streams in volume of water.

The abrupt change in the character of the country at the contact between the older Paleozoic sediments and the younger limestones is most pronounced, the former rocks standing up as a rampart across the whole area. In the isolated oval-shaped exposure of these rocks in the northeast corner of the Northern Shan States the same conditions hold, the older sediments rising up as a rugged, intricately dissected network of mountains out of the surrounding limestone country, which, by comparison, is of moderate relief, with wide valleys and rounded hills. The characteristic underground drainage of the limestone area has given rise to large sections, in which the topography consists of numerous sink holes of all sizes, inclosed basins in which the drainage disappears into the limestone. The same characteristic has also produced peculiar local topographic forms, such as hanging valleys without visible outlets and valleys with two distinct valley floors at different levels.

Certain sections of the granite area, in which the rock is of an extremely coarse-grained homogeneous nature, have weathered into a multitude of small, rounded hillocks without any definite drainage system. The streams wind sluggishly through the maze of small hills, often forming marshy lands. In this section the granite has weathered *in situ* often to a depth of several feet, leaving a soil composed of all the constituents of granite arranged in their normal position but unconsolidated.

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ARCHEAN SYSTEM

The Mogok gneiss in this area is similar in every way to this rock as described by Barrington Brown and J. W. Judd in the Ruby Mines district and Coggin Brown in his traverse from Bhamo in Burma to Teng-Yueh in Yunnan. Consequently the section mapped here allows one definitely to connect those two areas. The gneiss is present in a great variety of types and often assumes both schistose and granitoid forms. All phases, from extremely acidic to basic hornblende gneisses, are found. Bands of coarsely crystalline limestone are present, as in the other areas of this rock. In fact, this band of igneous and metamorphic rocks maintains a great regularity in its diversity, whether examined far to the south of Mandalay (east of Pyawbwe in latitude 20° 40′) or in the North at Teng-Yueh in latitude 25° 00′. Noteworthy at widely separated points are the crystalline limestone beds. These limestones are of considerable interest, first in that they house an extremely varied collection of minerals, over twenty-five mineral species having been identified by Barrington Brown and Professor Judd, and secondly in that Professor Judd has argued in favor of the inorganic origin of the limestone by means of the alteration of the unstable scapolite contained in the basal gneisses. It would appear that the practical continuity of this crystalline limestone, in a well-defined zone more than two hundred and fifty miles in length is almost conclusive evidence of its original organic origin.

GRANITE

The granite is discussed at this point because, although considerably younger than the gneiss, being in fact intrusive into the Cambrian sediments, it is always found either entirely within the gneiss or along its eastern edges. On the map no attempt is made to show the granite areas within the gneiss. There are, however, no grounds for not believing that the large mass of homogeneous granite shown as occurring between the gneiss and the older sediments is not genetically the same as the very numerous bodies of granite found entirely within the gneiss area. The granite is a normal biotite granite and extremely consistent in its mineral character over large areas; extreme variations occur, however, in the texture from coarse-grained to fine-grained types. Intrusive

dikes of a basic type are common and in some localities cover an extensive area.

Coggin Brown in his work in Yunnan did not attempt to map the granite separately from the gneiss, but from the text it appears very probable that the band of granite separating the gneiss from the younger sediments south of the Shweli extends well north of that river into Yunnan.

The peculiar type of topography and accompanying excessive disintegration over a portion of the granite area has been mentioned previously.

CAMBRIAN (CHAUNG MAGYI)

These rocks differ in no respect from the descriptions of them in the neighboring sections, as given by previous writers. They consist of slaty shales, phyllites, and quartzites, severely folded and of rapidly varying strike. The band of rocks of the Kao-liang series mapped by Coggin Brown in Yunnan just east of the Shweli River in latitude 24° 40′ is undoubtedly a direct continuation of the Chaung Magyi of the Northern Shan States.

LATE CAMBRIAN-ORDOVICIAN-SILURIAN BEDS

These formations are all grouped together, as it is possible to separate them only by careful paleontological work. The oldest rocks of this group are of the most interest, as it is in the section under discussion that they attain their greatest importance. They have been called the Pangyun beds by Coggin Brown. No fossils have been found in them, but as they are conformably followed by Ordovician beds they are themselves either late Cambrian or early Ordovician.

It has been generally assumed by other observers that a decided break exists between the non-fossiliferous Chaung Magyi and the fossiliferous Ordovician strata, but it seems possible that this may have been due to the fact that favorable exposures of the intervening rocks had never been observed. In this area numerous sections were examined from the Chaung Magyi to the Silurian rocks, and no decided break could be found, the Pangyun beds apparently filling in the period between the Chaung Magyi and the fossiliferous Ordovician. In this connection it is interesting to note that limestone beds are present at various points in the Pangyun series.

Coggin Brown in discussing the Kao-liang system states that "lower down the eastern slope of the divide (Irrawady-Salween), silver-grey phyllites are interbedded with dark slates and bands of limestone. In the latter occurrence there is a marked difference from the Chaung Magyi system of the Northern Shan States, which otherwise they greatly resemble, for the former system does not contain lime in any form." On the assumption that the Pangyun beds are a transition series between the Chaung Magyi and the younger fossiliferous beds it is possible that the beds observed by Coggin Brown belong to this series and thus represent the passage from the Kao-liang system to the Pu-Piao series.

The younger Ordovician and the Silurian beds closely resemble those described by La Touche for the area to the south. They consist of sandstones, shales, marls, and occasional limestone beds. A detailed study of these beds in this section, with careful paleontological work, would undoubtedly allow of their being separated into their smaller subdivisions, as has been done by La Touche for the rest of the area.

The Pu-Piao series and the Silurian system in Yunnan of Coggin Brown are assumed as being analogous with the group of beds mapped here as lying between the Chaung Magyi and the younger limestones, with the slight difference that the bottom member (Pangyun beds) may belong both to the Kao-liang and the Pu-Piao.

DEVONIAN-CARBONIFEROUS-PERMIAN (PLATEAU LIMESTONE)

It has not been attempted to differentiate this formation, which covers a period from the Devonian to the Permian, into an upper and lower, as has been done by La Touche in the southern area. It is a direct continuation of the Plateau limestone mapped by him, and similar to it in all respects. In all the eastern section of the area it completely covers the older rocks except at two points, one in the northeast corner, where an eroded anticlinal mass has exposed the older sediments down to the Chaung Magyi, and the second in the gorge of the Salween, which river has cut its way down through the limestone and Silurian and Ordovician sediments into the Cambrian. At neither of these points are igneous or metamorphic rocks exposed.

As shown, this broad band of limestone continues into Yunnan and is thus directly correlated with the Devonian and Permo-Carboniferous limestone of that province.

JURASSIC (NAM YAU BEDS)

At one point in approximate latitude 23° 47′ longitude 98° 15′ on the flanks of the dome-shaped anticline in which the older sediments are exposed, beds of coarse conglomerates, with the pebbles largely of limestone, were noted. A short distance from this point extensive beds of red sandstone were encountered lying above the Plateau limestone. Their position and character are fairly strong evidence in assigning them to the Nam Yau, but the scant opportunity for examining them makes their definite determination unadvisable. This is especially true as they also resemble the Red Bed series of Yunnan (Permian-Triassic), as described by Coggin Brown, and may possibly represent a southern outlier of those beds.

No Jurassic beds have as yet been identified in Yunnan.

TERTIARY

Fairly extensive deposits of Tertiary beds are present in the Nam Tu valley, but they were not noted elsewhere, although it is possible that small remnants are present in some of the other valleys in the Plateau limestone. They are found as unconsolidated sands and clays and often contain extensive deposits of lignite and sub-bituminous coal.

RECENT

All the more prominent river valleys are covered with deposits of recent alluvium, probably with the exception of the Shweli valley in the Namhkam area, always of fluviatile origin. In the case of the Shweli valley the broad plain about thirty miles long, with an average width of five or six miles, probably represents an old lake bed similar to the numerous ones which have been noted in Yunnan. Recent elevation with consequent renewed erosion by the Shweli has largely concealed its former character.

It has not been attempted to show these deposits on the accompanying map, as it only tends to confuse the relations of the underlying consolidated formations.

ON THE ACCURACY OF THE ROSIWAL METHOD FOR THE DETERMINATION OF THE MINERALS IN A ROCK

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Some years ago Julien[1] expressed a doubt as to the accuracy of the Rosiwal method in the determination of the percentage composition of rocks in general. He thought, if the fragments were equicubical, that d, the measured average diameter of the mineral plates, might give correct results, but for unequicubical grains the value d^3 should be used, and for rounded grains,[2] thick lenses, or short spindles, $.7854\sqrt{a}$ or d^2. For schistose rocks with flakes and interlaminae parallel and of equal thickness, he suggested d^2, for prisms or blades with parallel interlaminae, $d' = \sqrt[3]{l \times b \times t}$, where l, b, and t are the length, breadth, and thickness of plates.

Williams,[3] several years later, studied the comparative accuracy of various methods, using a pink granite from Westerly, Rhode Island, with grains ranging from 1.5 to 5 mm. in diameter. Several determinations were made in each experimental method and the results were averaged and tabulated with the calculated results as shown in Table I.

The first column is calculated from the chemical analysis and is practically the norm, except for the small amount of biotite. The second column represents the percentages of the different minerals obtained by separation according to their specific gravities in Sonstadt's solution. The agreement of this determination with the preceding is fairly close. The third column is based upon

[1] A. A. Julien, "Genesis of the Amphibole Schists and Serpentines of Manhattan Island, New York," *Bull. Geol. Soc. Amer.*, XIV (1902), 460–68.

[2] Julien gives $.7854\sqrt{a}$ or d^2 for this value. Williams gives $.5236d^3$, the volume of a sphere, as Julien's (possibly later) figure.

[3] Ira A. Williams, "The Comparative Accuracy of the Methods for Determining the Percentages of the Several Components of an Igneous Rock," *Amer. Geol.*, XXV (1905), 34–46.

microscopic measurements of the diameters of grains in thin section made according to the Rosiwal method, the results thus obtained being multiplied by the respective specific gravities to give weight percentages. (Personally the present writers prefer to transfer the specific gravity determinations into volume percentages rather than the reverse, since one estimates the composition of a rock by volumes and not by specific gravities.) The fourth column represents six different photomicrographic prints, made of different parts of the slide, which were dissected and weighed according to the Delesse-Sollas-Joly method. The weights of the fragments of paper were assumed to be proportional to the areas, therefore to the

TABLE I

	I Calculated from Chemical Analysis	II Heavy Solution	III Measurements of Diameters Rosiwal Method	IV Photomicrographs of Areas	V Areas (d^2) Measured by Microm. Ocular	VI Calculations of d^3 from Column III	VII Calculations of d^3 from Column V
Quartz	35.90	34.25	19.02	23.23	19.90	1.41	12.14
Orthoclase	34.48	32.47	43.65	43.64	43.67	56.04	49.92
Plagioclase	24.99	26.91	32.90	32.90	32.90	42.24	37.31
Mica	0.26	5.68	4.43	0.25	3.52	0.31	0.63
Magnetite	2.60						
Hematite	1.10						

volumes of the minerals. The percentages were computed as before. The fifth column represents measurements of areas made by means of a net-micrometer ocular, as originally used by Rosiwal; the number of squares included within the boundaries of the different minerals being counted. The areas again were assumed to be proportional to volumes. The sixth column was obtained by cubing the values in column III and reducing the sum to 100. The last column represents d^3 calculated from the value of d^2 in column V.

Williams pointed out the close agreement between the composition calculated from the chemical analysis and the results obtained with Sonstadt's solution on the one hand, and that obtained by the Rosiwal method and the measurement of areas on the other. The two sets of values, however, do not agree. He remarked that "though the absolute volumes (of the microscopic methods) may not be correct, using d as indicated, relative volumes as expressed

in percentages may nevertheless give as significant results as if the actual value of d were known." The results of columns VI and VII indicate that d^3 cannot be used for calculating the percentage composition when d is the measured width of the mineral grains in the thin section.

Williams concludes that,

> any one of the direct measurements with the microscope does not appear to fulfill even approximately the necessary conditions for a statement of the complete quantitative composition," but that "heavy solutions are a convenient and readily applicable method of separating the minerals of a rock and may be valuable in determining quantitative relations. . . . . The accuracy of the results will be directly proportional to the coarseness of grain and the readiness with which the minerals can be separated.

So far as the writers are aware, no other comparisons have been made between the specific gravity method and that of Rosiwal. Contrary opinions to those just quoted are held by many petrographers. Thus in Table II we have the comparison of a

TABLE II

	I Calculated Composition from Analysis	II Rosiwal Volume Analysis: First Specimen	III Weight Percentage: First Specimen	IV Rosiwal Volume Anal.: Second Specimen	V Weight Percentage: Second Specimen
Quartz	22.86	23.17	22.55	20.97	20.34
Orthoclase	18.35	18.62	17.57	21.07	19.82
Ab_3An_2	39.74	43.10	42.47	42.29	41.48
Biotite	10.92	8.87	9.77	8.15	8.94
Hornblende	3.56	3.78	4.44	4.84	5.67
Pyroxene		1.97	2.37	2.07	2.50
Magnetite	1.86	.40	.76	.54	1.02
Pyrite, etc.	1.86	.04	.07	.02	.04

computation from chemical data of mineral composition with measured linear dimensions according to the Rosiwal method made by Cross, Iddings, Pirsson, and Washington[1] for the Butte "granite."

In Table II, columns I, III, and V should be compared. The authors state that a small amount of pyroxene was intergrown with

[1] Cross, Iddings, Pirsson, and Washington, "A Quantitative Chemico-Mineralogical Classification and Nomenclature of Igneous Rocks," *Jour. Geol.*, X (1902), 681–82. *Ibid.*, *Quantitative Classification of Igneous Rocks* (Chicago, 1903), p. 286.

the hornblende and was probably included in the analyzed hornblendic material. The two minerals are, therefore, calculated together. There can be no question about the success of the Rosiwal determinations in this case. Cross, Iddings, Pirsson, and Washington[1] say: "It is possible . . . . to determine very closely the proportions of the minerals present. . . . ." This determination proves either the accuracy of the Rosiwal method or, since it is only a single example, an almost exact compensating error.

Among other petrographers who have found the microscopic methods of sufficient accuracy are Barrell,[2] who determined his constituents by a somewhat simpler, though less accurate, method. He says:

> The field of view of the microscope is divided into quadrants by the cross-hairs, and these are mentally divided into sectors which are thirds, fifths, or smaller fractions. By taking such a power of objective that the component to be estimated is represented in the field of view by a fair number of crystals, the latter can be mentally collected together and packed into one quadrant, and the fraction which it fills estimated. . . . . In the case of holocrystalline rocks, where the writer has been enabled to check this method of estimating the mineral and chemical composition by comparison with laboratory analyses, *it is found that the error in any one element should be less than 1 per cent and is often less than one-half per cent.* [The italics are ours.]

Robinson[3] compared the Rosiwal measurements of a porphyritic dacite with the composition calculated from an analysis and found that

> there is a difference of 3.2 per cent between the total salic components, including the excess of alumina in the calculated mode, and of 2.6 per cent between the dark components. . . . . The comparison will give an idea of the accuracy of the Rosiwal method as applied to porphyritic lavas containing small amounts of minerals of highly variable size.

Tyrrell[4] says:

> The graphic method of quantitative mineral measurement invented by Rosiwal yields sufficiently accurate results for classificatory purposes in the

[1] *Ibid.*, p. 204.

[2] Joseph Barrell, "Microscopical Petrography of the Elkhorn Mining District, Jefferson County, Montana," XXII An. *U.S. Geol. Surv.*, Pt. II, 1901, pp. 512–13.

[3] Henry Hollister Robinson, "The San Franciscan Volcanic Field, Arizona," *U.S. Geol. Surv., Prof. Paper 76*, 1913, p. 121.

[4] G. W. Tyrrell, "A Review of Igneous Rock Classifications," *Science Progress*, 1914, pp. 74–75.

great majority of types. . . . . Notwithstanding the opinion of Williams, the Rosiwal method of estimation is capable of giving extremely accurate results. The writer . . . . has found the chemical composition calculated from the results of the Rosiwal measurements to be strikingly accordant with that obtained by ordinary chemical analysis.

In view of Williams' apparently careful study and rejection of the Rosiwal and other microscopic methods, and of the increasing use made of volumetric determinations of rock constituents by other petrographers, it was thought desirable to repeat the experiments with all possible precautions against errors in both the Rosiwal and the heavy solution methods. Williams' study is apparently the only one in which there was a comparison of the percentages determined by the microscopic measurement method and an actual separation of the minerals; all others are comparisons between the former and recalculated chemical analyses, with all the possible errors in allotting constituents due to the uncertain composition of the dark constituents and the possible soda content of the orthoclase.

The material chosen for the experiment by the present writers was the Butte "granite." It was selected because it had been chemically analyzed, because there was available ample material from the original locality, and because there were on hand six thin sections and the two determinations by the Rosiwal method made by others as mentioned above, and five determinations by students on one slide (Table III, column I). Furthermore, the material is of fairly uniform grain and composition in widely separated localities, thus giving a fairer test than would a rock differing possibly in different sections and thus probably different from the material analyzed.

The six different sections were measured by the Rosiwal method from one to five times each, fourteen determinations being made in all. The average of each slide, reduced to weight percentages, is shown below. In Table III the first six columns represent the six sections; the number in parentheses after each indicates the number of times it was measured. The seventh and eighth columns are the determinations taken from Cross, Iddings, Pirssons, and Washington and quoted above. The variations between the read-

ings obtained for the different sections are possibly due to differences in the sections themselves, the grain of the rock being coarse enough to show slight variations. The last column shows the average of the sixteen determinations, and not the average of the averages.

TABLE III

	I (5)	II (1)	III (2)	IV (3)	V (1)	VI (2)	Cross, Iddings, Pirrson, and Washington		Average
Quartz	20.31	22.4	23.79	24.76	20.3	17.64	22.55	20.34	21.6
Orthoclase	25.31	31.6	18.15	30.77	28.5	29.11	17.57	19.82	25.8
Plagioclase	38.75	32.9	43.00	25.18	32.3	32.01	42.47	41.48	35.6
Biotite	8.98	8.3	8.35	9.70	10.8	10.47	9.77	8.94	9.2
Hornblende	4.65	4.4	5.81	7.02	5.2	7.47	4.44	5.67	5.6
Augite	.70	.2	.....	1.01	1.3	2.76	2.37	2.50	1.1
Magnetite	.74	.....	.63	1.50	1.2	.58	.76	1.02	.8
Apatite	.03	.1	.10	.....	.....	.....	.....	.....	.0
Titanite	.04	.....	.09	.....	.....	.....	.....	.....	.0
Pyrite	.55	.....	.04	.....	0.3	.09	.07	.04	.2
Zircon	.03	.....	.....	.....	.....	.....	.....	.....	.....
	99.99	99.9	99.96	99.94	99.9	100.13	99.98	99.81	99.9

For the separation of the constituents by mechanical means, several methods were employed. The magnetite was first removed by means of an electromagnet.[1] By repeating the process the material removed was practically pure. The biotite was next separated by Rosenbusch's[2] method of shaking the rock powder from an inclined sheet of semi-glazed paper. A remarkably clean separation resulted as shown by microscopic examination, only a few flat hornblende flakes being included as impurities. The remaining material was now placed in a Brögger-Harada[3] tube with about a half-pint of Sonstadt's (potassium-mercuric-iodide) solution, and enough water was added to bring down the hornblende and augite. For the purpose of these experiments it was not necessary to separate these two minerals, so it was not attempted. With these minerals the zircon, apatite, and titanite came down. Thus far the separation was easy; the difference in color between the heavy minerals and those remaining clearly showed when

[1] The instrument is illustrated and the method described in Johannsen's *Manual of Petrographic Methods*, 1918, Fig. 725, and p. 540.

[2] *Ibid.*, p. 557. [3] *Ibid.*, p. 551.

the separation was complete. The separation of the plagioclase (Sp. gr. 2.68) from the quartz (Sp. gr. 2.65) was the most difficult. As an indicator, therefore, a small Herkimer County quartz crystal was placed in the solution, which was then diluted until the crystal began to sink, after which a very small amount of concentrated solution was added to make it slowly rise to the top. This adjustment between the specific gravity of the quartz and that of the liquid is here so delicate that a slight change in the density of the solution, such as results from a slight change in the temperature of the room, caused the quartz, which has a very small coefficient of expansion, to settle during the night and rise again during the day. When the equilibrium was established, the plagioclase was removed, washed, dried, and weighed as in the other cases. The quartz was brought down by adding enough water to bring down the indicator. The final material was the orthoclase.

The greatest objection to the specific-gravity method seems to be the impossibility of preparing powder which consists of homogeneous material. In many cases material of one kind will cling to grains of another and will increase or decrease their specific gravities. The small amount of mixed material shows up very clearly in the separation, especially when between light and dark minerals, for the mixed heavier grayish material will come down before the pure white mineral, or, on the other hand, the precipitated dark mineral will be covered with a thin layer of material that is grayish. The probabilities are that the two errors compensate. The material should be crushed fine enough to separate each constituent from every other, but not so fine as to produce dust, since some minerals pulverize much more readily than others and a different proportion of each will be lost, destroying the accuracy of the result. A happy medium must therefore be taken between purity and selective sieving, since absolute purity cannot be expected. Microscopic examination of a small amount of the material of a certain size will readily make it possible to determine whether or no the rock has been crushed fine enough to produce a good separation of the constituents. For the following experiments various-sized grains were used, as indicated at the top of each column in Table IV. After crushing and sifting, the total samples weighed

140–150 gms. This was quartered, and one-fourth of each quarter was used to make two samples for determination. For this particular rock, grains passing through a 60-mesh sieve and remaining on a 100 mesh seemed to be very suitable.

TABLE IV

	I Sp. gr.	II Mesh 80–100	III Mesh 80–100	IV Mesh 60–100	V Mesh 60–100	VI Mesh 60–100	VII Mesh 60–100	VIII Average
Magnetite	5.10	1.38	1.09	1.42	1.12	1.36	1.30	1.26
Biotite	3.00	11.10	9.49	9.94	9.74	9.88	9.72	9.98
Hornblende	3.20	6.66	6.93	6.66	6.44	6.31	6.25	6.54
Augite	3.30							
Plagioclase	2.68	37.87	37.10	34.60	31.65	32.82	33.40	34.57
Quartz	2.65	19.21	21.11	21.35	23.22	24.65	23.70	22.21
Orthoclase	2.57	23.07	24.25	26.00	27.06	25.02	26.06	25.25
		99.29	99.97	99.97	99.23	100.04	100.43	99.81

Comparing now the final results of each of the three methods, we have the results given in Table V.

TABLE V

	Calculated from Analysis	Weight Percentage Rosiwal	Heavy Solution
Quartz	22.86	21.6	22.21
Orthoclase	18.35	25.8	25.24
Plagioclase	39.74	35.6	34.57
Biotite	10.92	9.2	9.98
Pyribole	3.56	6.7	6.54
Magnetite	1.86	.8	1.26
Pyrite, etc.	1.86	.2	.....
	99.15	99.9	99.83

The amount of quartz in the calculated analysis is practically the same as in the specific-gravity determination, and the Rosiwal value is only slightly less.

The orthoclase is low in the calculated analysis and practically the same in columns 2 and 3, while the calculated plagioclase is high as compared with the other two determinations. This is unquestionably due to the fact that the orthoclase carries soda. In the computation of the analysis by Cross, Iddings, Pirsson, and

Washington (p. 225), orthoclase was taken as $K_2O \cdot Al_2O_3 \cdot 6SiO_2$ in the place of the actual composition. In all probability the orthoclase-plagioclase percentages of the Rosiwal and specific-gravity determinations are more nearly those of the actual minerals present than those computed from the chemical analysis. It will be seen that the sums of the feldspars, 58.09, 61.4, and 59.81, are not greatly different.

The sums of the leucocratic constituents in the three columns, 80.95, 83.00, and 82.02, are also close together, as are the biotite and magnetite values.

The only noteworthy variations in any of the determinations are in the values of the remaining constituents—the pyribole and the pyrite. Here the values for the former are 5.42, 7.5, and 6.54, and for the latter, 1.86, 0.3, and 0. For the sum of the two constituents in each column, however, we have 7.28, 7.8, and 6.54. In the first place the sum of all the constituents in the analysis calculated by Cross, Iddings, Pirsson, and Washington in column 1 is only 99.15, as against 99.9 and 99.81 in the other two columns; consequently the first-column values should be slightly increased. The calculated amount of pyrite (1.86) is greatly in excess of that seen in any slide or in the hand specimen. The fraction of 1 per cent given by the thin section is much more nearly correct. When the greater part of the pyrite is added to the pyribole in column 1, the values are more nearly the same. In the specific-gravity determination the magnetite and biotite were removed before the pulverized material was placed in the Sonstadt solution, which was then diluted until the pyribole and the small amounts of pyrite, apatite, and zircon present came down. Therefore these latter minerals are included with the pyribole in that column. The rock analysis and the thin sections were clearly from material slightly more melanocratic than the pulverized rock used in the specific-gravity determination, as is shown by the difference between the leucocratic-melanocratic ratio of columns 1 and 2 as against column 3.

Reviews

Manual for the Oil and Gas Industry under the Revenue Act of 1918. By the U.S. Bureau of Internal Revenue of the Treasury Department, 1919. Pp. 136, figs. 13.

To assist the taxpayer of the oil and gas industry in correctly and expeditiously preparing his Federal tax returns, the Bureau of Internal Revenue has prepared a "Manual for the Oil and Gas Industry Under the Revenue Act of 1918." Although the endeavor has been made to anticipate all questions that may be asked regarding the law and regulations, and the latter have been amplified when it was deemed necessary to obtain the desired result, it is recognized that such a manual is only general, and cannot cover all cases that may exist. The *Manual* is based largely upon information gathered during the fall of the year 1918 by a corps of geologists, technologists, and engineers. The investigation was undertaken primarily to furnish a basis for arriving at valuations, and depletion and depreciation deductions, in connection with oil and gas properties.

The *Manual* (136 pages and 13 plates) is now being distributed among taxpayers of the oil and gas industry. For the purposes of the *Manual*, the country is divided into seven districts, each of which was handled by a supervisor and several assistants. These are: (1) the Appalachian Field, (2) the Lima-Indiana and Illinois fields, (3) the Mid-Continent Field, (4) the Northern Louisiana Field, (5) the Gulf Coast Field, (6) the Rocky Mountain District, and (7) the California Field.

The book consists of three parts: *Part I* deals directly with the Law and Regulations, *Part II* with the question of depreciation, and *Part III* consists of descriptions and methods of estimating underground oil reserves, especially by means of production curves. A collection of curves and tables covering many of the oil fields and pools in the United States accompanies the text. They are intended as a suggestion for the guidance of the taxpayer in the computation of his depletion allowance.

The work of compiling and editing the material in the *Manual* was done largely by A. D. Brokaw, J. L. Darnell, and L. G. Donnelly. The investigations leading to the preparation of the *Manual* and its compilation and publication were under the general supervision of Ralph Arnold, Chief of the Oil and Gas Section.

Copies may be obtained by application to the Commissioner of Internal Revenue, Washington, D.C.

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